PART TWELVE

BRIEFING CHARTS

PART TWELVE

BRIEFING CHARTS

TABLE OF CONTENTS

PART TWELVE

BRIEFING CHARTS

I. INTRODUCTION

In this Part, we have included copies of the flip charts and overhead projector viewgraphs used in the two briefings we conducted as part of this seismic detection and location task. The first one was an overview and problem definition briefing given to the seismic consultants on September 7, 1972. The second was a formal oral presentation of study results to technical staff members of the Pittsburgh Mining and Safety Research Center on November 21, 1972.

II. PROGRAM BRIEFING FOR SEISMIC CONSULTANTS 7 SEPTEMBER 1972

SEISMIC LOCATION OF ISOLATED MINERS
Arthur D. Little, Inc.

In order to provide the seismic consultants with a clear and concise:

a) definition of the seismic miner location problem;

b) summary of the relevant background information regarding the Bureau's seismic location program to date; and

c) identification and assignment of specific tasks;

we prepared and gave the consultants a comprehensive briefing. This briefing consisted of a flip chart presentation, complemented by the use of film, slides, and viewgraphs, and culminated in an interactive discussion of the problem, specific tasks, and consultants' individual areas of interest and corresponding assignments. In short, the seismic briefing was organized into the six parts listed below, and summarized in this Part by reproductions of the briefing visual aids.

A. OPENING REMARKS - ADL

B. INTRODUCTION TO COAL MINE DISASTERS - BUMINES

C. OVERVIEW AND STATUS OF SEISMIC LOCATION PROGRAM - BUMINES

D. FORMULATION OF THE MINER SEISMIC LOCATION PROBLEM - ADL

E. DESIRED END PRODUCT AND SCHEDULE OF PRESENT EFFORT - ADL

F. IDENTIFICATION AND DISCUSSION OF MAJOR TASKS AND TASK ASSIGNMENTS - ADL/PARTICIPANTS

A. OPENING REMARKS

ARTHUR D. LITTLE, INC. - R. LAGACE

OBJECTIVE

DETECTION AND LOCATION
OF MINER
BY SEISMIC MEANS

PRESENT EFFORT

DETERMINE:

- HOW AND HOW WELL OUR OBJECTIVE CAN BE ACHIEVED

IN PARTICULAR:

IDENTIFY WHAT CAN BE DONE AND HOW WELL -- BY SEISMIC MEANS -- TO:

- DETECT A MINER
- LOCATE A MINER TO WITHIN A SECTION
- LOCATE A MINER TO WITHIN AN ENTRY WIDTH

B. INTRODUCTION TO COAL MINE DISASTERS

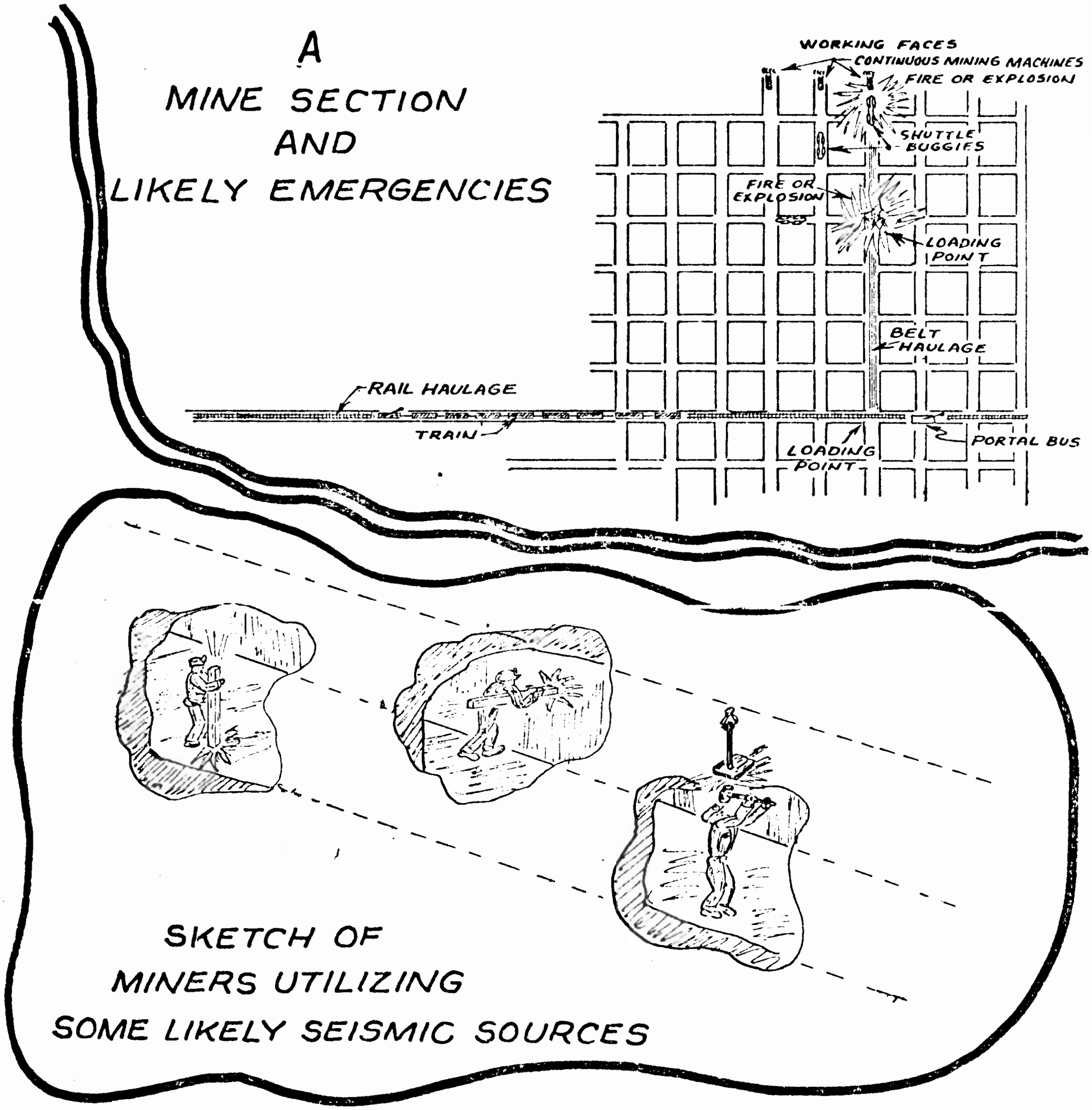
U.S. BUREAU OF MINES - H. PARKINSON, PMSRC

This part of the briefing included:

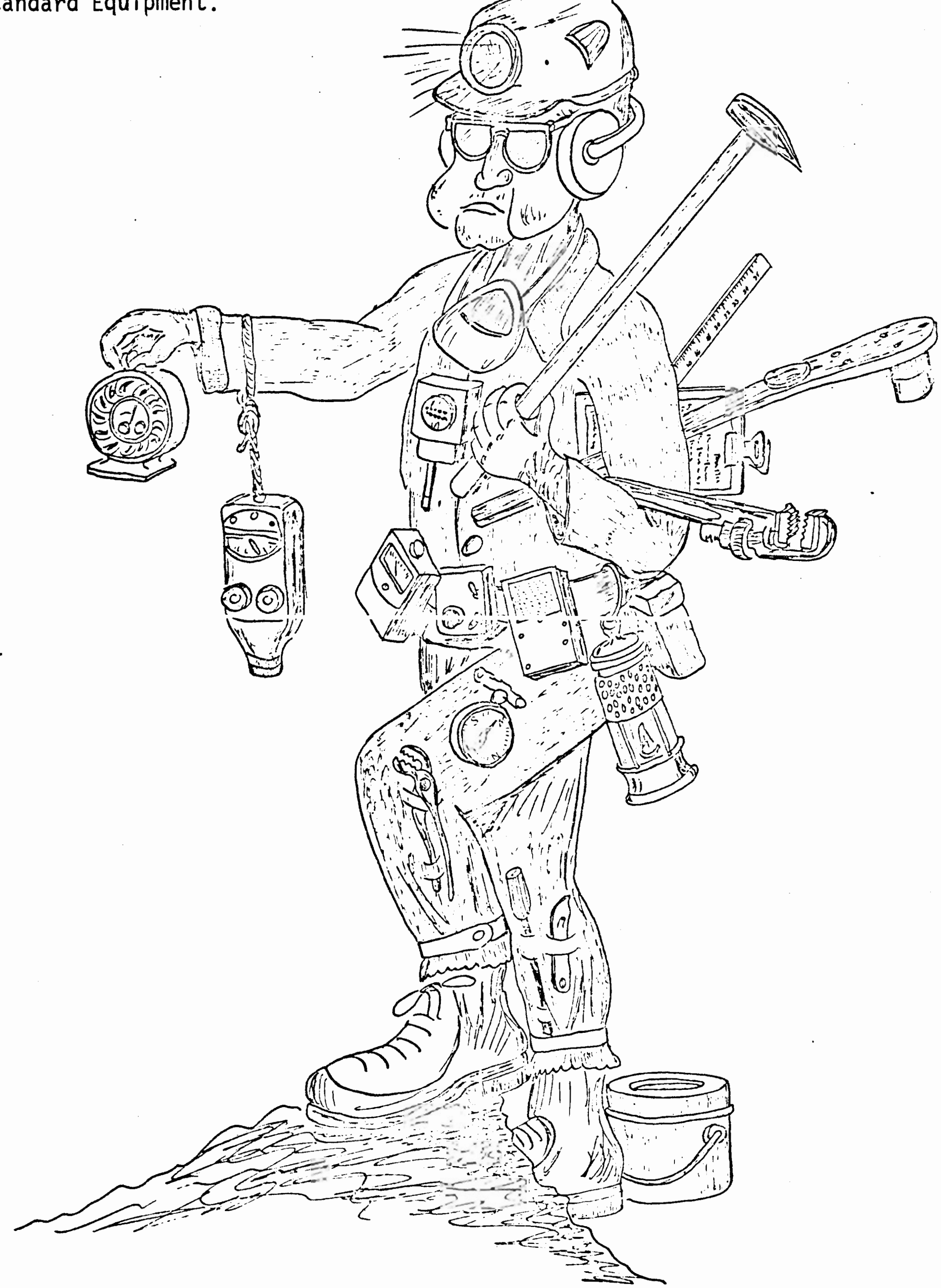
1. Viewing of the Bureau film: SAFETY PRACTICES IN LOW COAL MINES, with special narration by H. Parkinson.

2. Viewing color slides of the U.S. Steel Mine site used for the demonstration of the Coal Mine Rescue and Survival System.

3. Discussion of Coal Mine Layouts, Activities, and Disasters with the Aid of Actual Mine Maps, and the Visuals included in this section.


A
MINE SECTION
AND
LIKELY EMERGENCIES
WORKING FACES
CONTINUOUS MINING MACHINES
FIRE OR EXPLOSION
SHUTTLE BUGGIES
FIRE OR EXPLOSION
LOADING POINT
BELT HAULAGE
RAIL HAULAGE
TRAIN
LOADING POINT
PORTAL BUS
SKETCH OF
MINERS UTILIZING
SOME LIKELY SEISMIC SOURCES

An example in the extreme of what cannot be imposed on the miner. Namely, the miner CANNOT be expected to carry or have attached to his person, a Special Seismic Signaling Device as Standard Equipment.



C. OVERVIEW AND STATUS OF

SEISMIC LOCATION PROGRAM

U.S. BUREAU OF MINES - J.POWELL, PMSRC

O U T L I N E

WHERE ARE WE NOW?

- HISTORY
- PHILOSOPHY AND RATIONALE
- SYSTEM SET-UP
- EXPERIMENTS AND INVESTIGATIONS
- RESULTS

NAE RECOMMENDATIONS

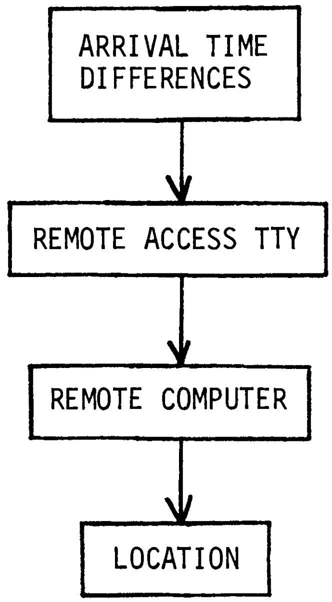
AND

REQUIREMENTS

REQUIRED:	50 FT. ACCURACY
THOUGHT TO BE ATTAINABLE:	25 FT. ACCURACY

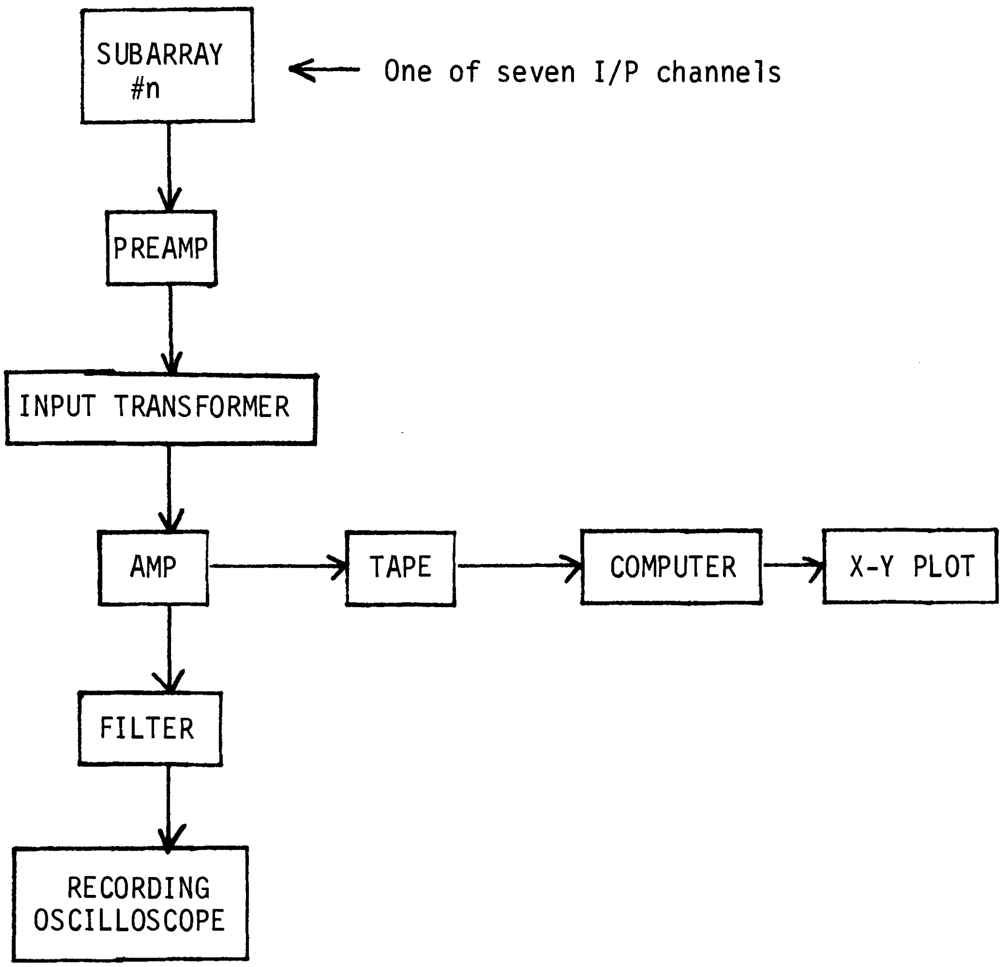
(2 millisec. timing error at 10,000 fps velocity
$\equiv$ 20 ft. error)

SYSTEM (LOCATING)

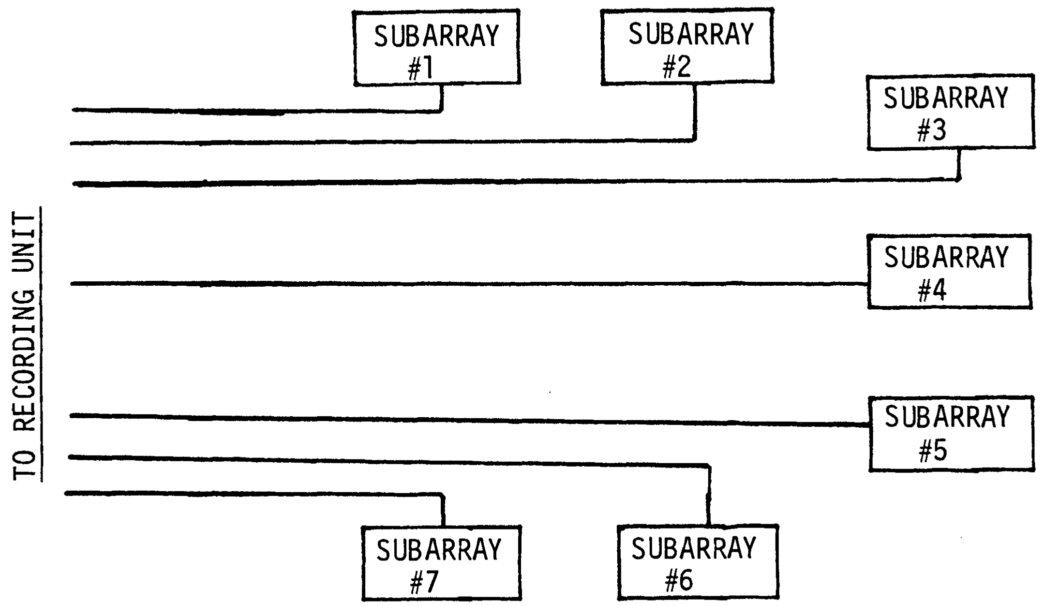


SYSTEM

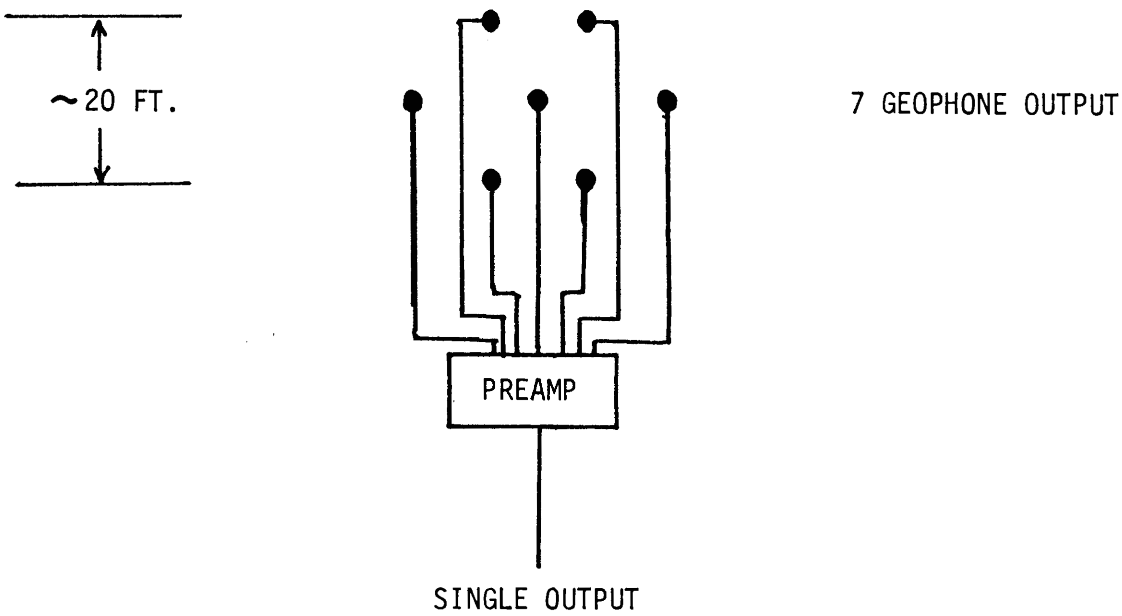
RECORD UNIT, NORMAL MODE



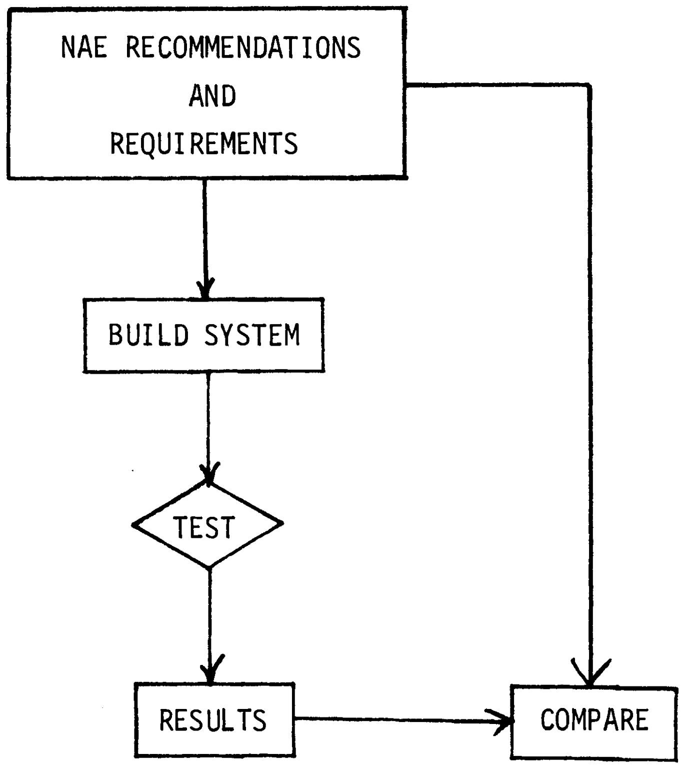
SYSTEM (ARRAY)



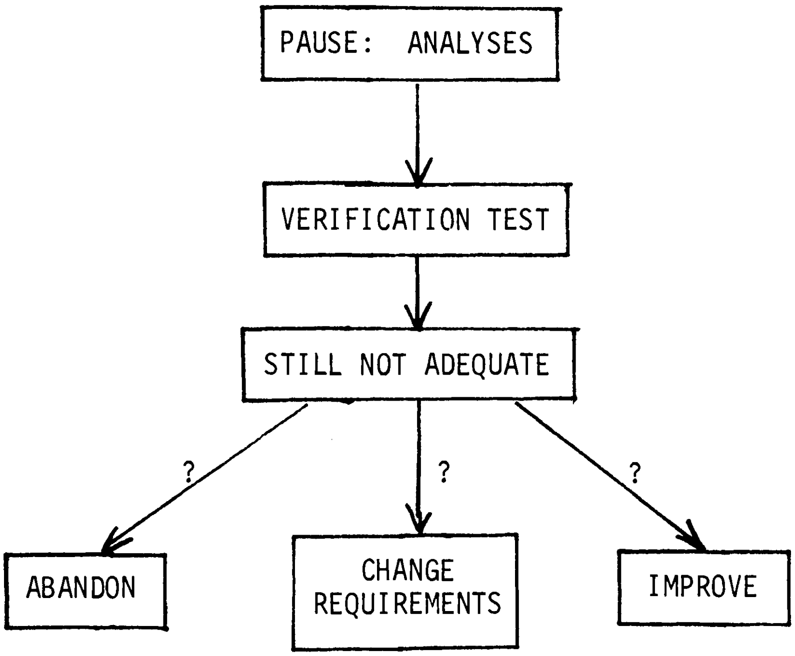
SYSTEM (SUBARRAY)



HISTORY - (A)


NAE RECOMMENDATIONS
AND
REQUIREMENTS
BUILD SYSTEM
TEST
RESULTS
COMPARE

HISTORY - (B)


PAUSE: ANALYSES
VERIFICATION TEST
STILL NOT ADEQUATE
?
?
?
ABANDON
CHANGE REQUIREMENTS
IMPROVE

T E S T

PHILOSOPHY: VARIETY IN

- MINE TYPES
- GEOGRAPHIC AREAS

(ASSUMED SYSTEM WOULD USUALLY WORK)

RESULTS: FAILED NAE REQUIREMENTS

PAUSE - ANALYSES

E.G.,

- THEORETIC EXAMINATION OF SOURCES
- EXAMINATION OF PRE-AMP DESIGN
- COMPLETE LIST IN SEISMIC APPENDIX
  (Westinghouse FY 1972 Report)

VERIFICATION TEST

SIX (6) WEEKS AT EXPERIMENTAL MINE

(50 FT. OVERBURDEN), BRUCETON, PENNSYLVANIA

- Not Always a Realistic Test

<u>WHAT NEXT?</u>

- ABANDON - E.G., RELY ON E.M. METHODS
- CHANGE REQUIREMENTS - E.G., ONLY NEED TO KNOW SECTION
- IMPROVE - Y O U

CHOICE WILL BE MADE WITH <u>YOUR</u> HELP

D. FORMULATION OF THE MINER SEISMIC LOCATION PROBLEM

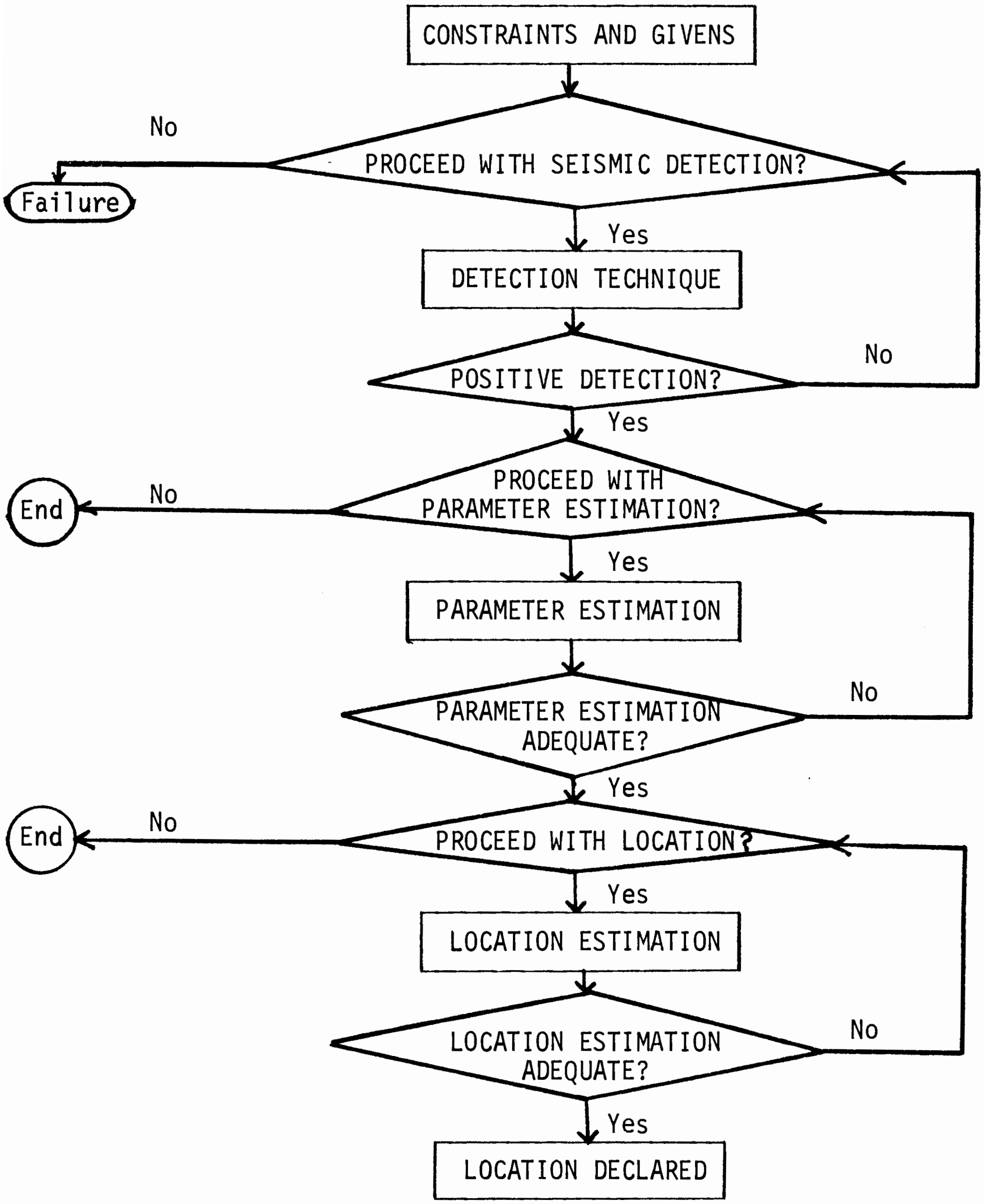
ARTHUR D. LITTLE, INC. - M. ROETTER

CONSTRAINTS AND GIVENS

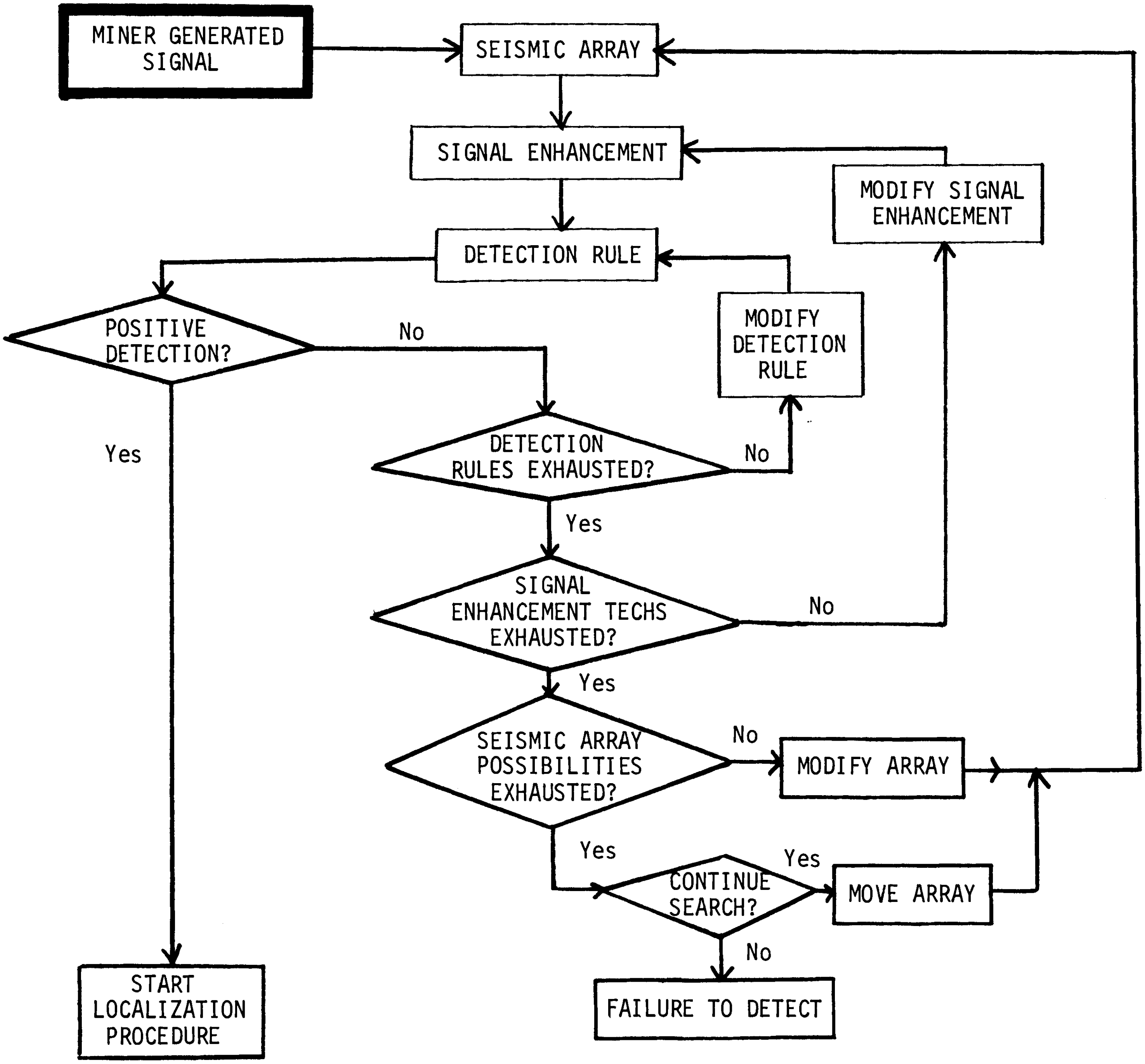
INDUCED BY:

- MINE
- MINERS
- SEISMIC SYSTEM
- OVERALL RESCUE EFFORT

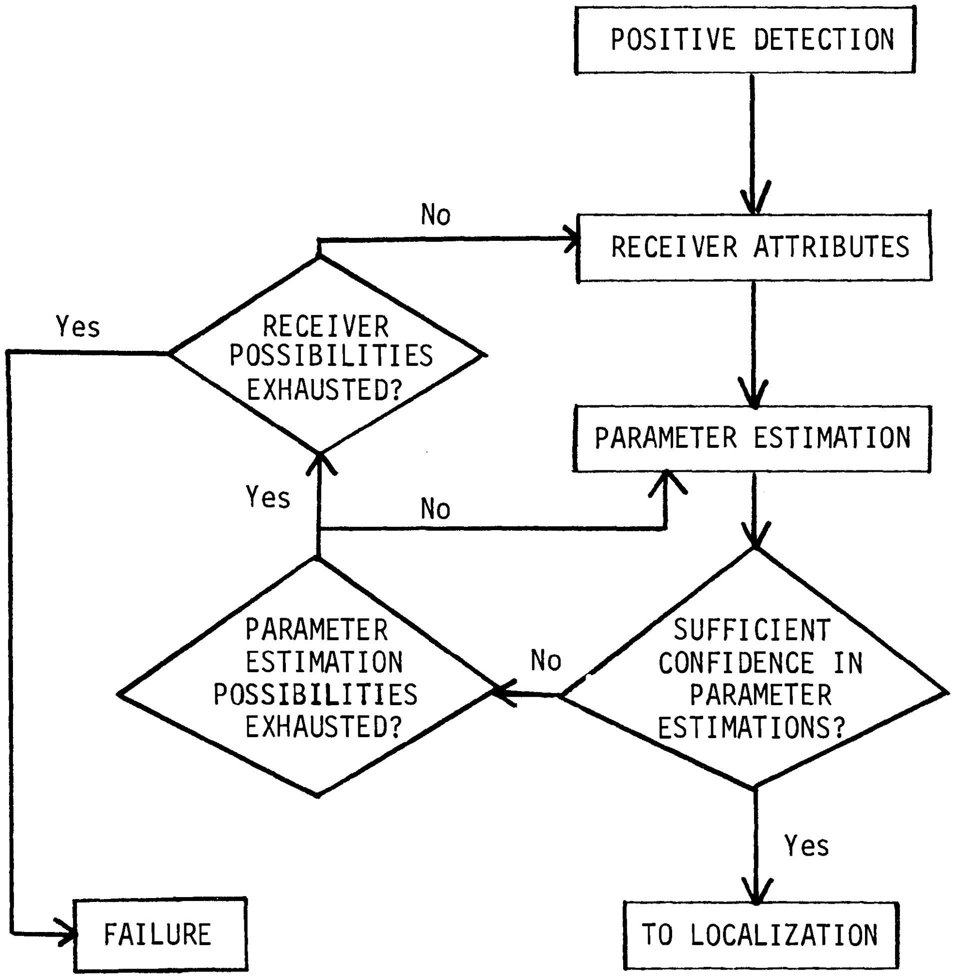
FORMULATION OF PROBLEM



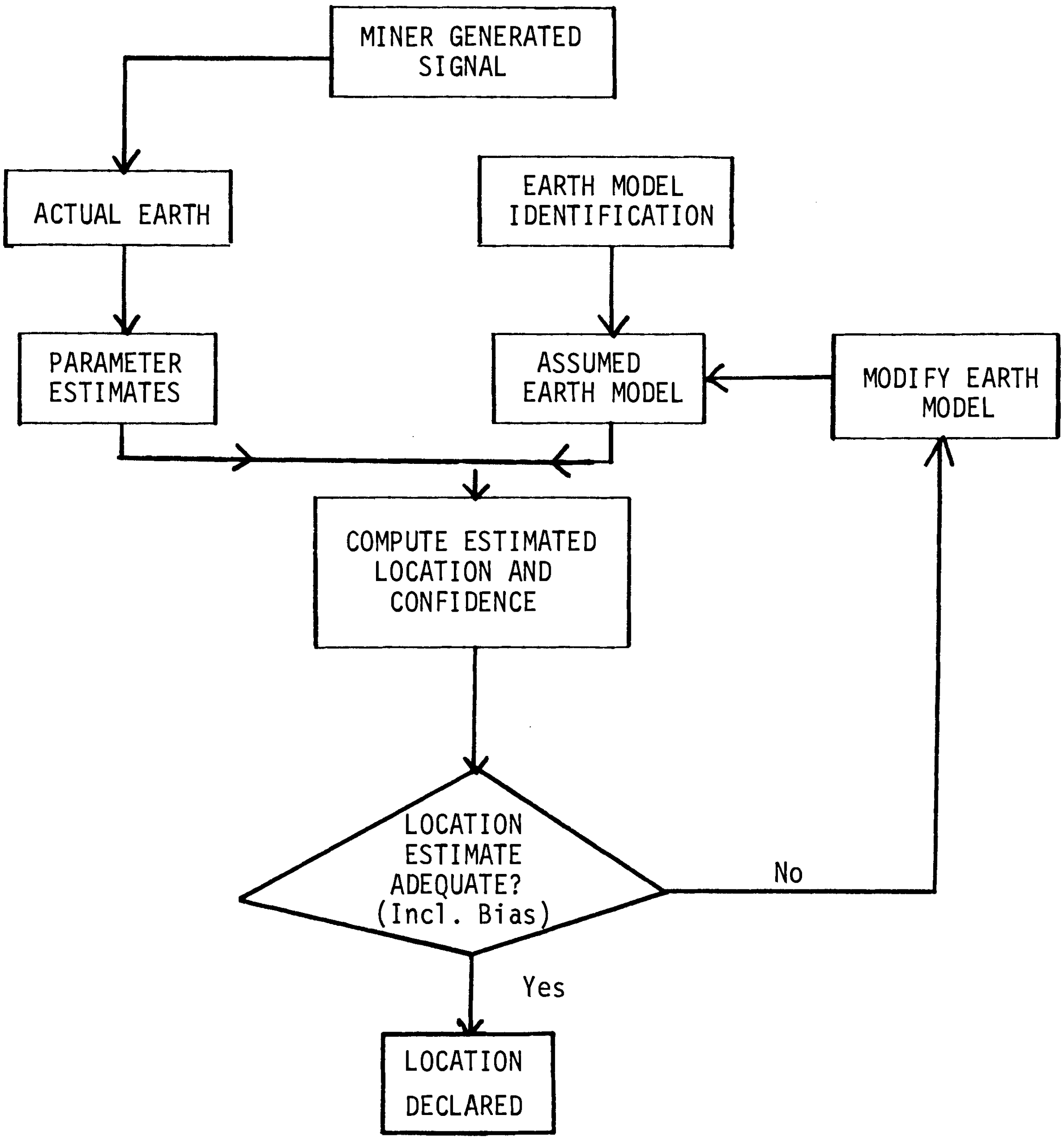
DETECTION OF MINER



PARAMETER ESTIMATION



MINER LOCALIZATION



SEISMIC LOCATION SYSTEM:

GENERAL GROUND RULES

- HARDWARE: FIELD SUITABLE AND RAPIDLY DEPLOYABLE
- SYSTEM CONSTRAINED TO PRESENT STATE-OF-THE-ART TECHNIQUES AND HARDWARE
- SYSTEM OPERATION FROM SURFACE
- SYSTEM SELF-CONTAINED IN ITS OPERATION AND CALIBRATION
- SYSTEM CAPABLE OF PRODUCING TIMELY LOCATION ESTIMATES
- SYSTEM OPERATION COMPATIBLE WITH AND COMPLEMENTARY TO OVERALL RESCUE EFFORT

<u>KEEPING IN MIND THE</u>
<u>IMPACT OF</u>
<u>INVESTMENTS IN</u>

- EQUIPMENT
- TRAINING
- SITE CALIBRATION-PREPARATION

<u>ON</u>
<u>PERFORMANCE</u>
<u>AND</u>
<u>COST</u>

SEISMIC LOCATION SYSTEM:

SPECIFIC GROUND RULES

THE MINER AND HIS MESSAGE

1) The miner has uncertainty as to his true location.
2) The miner's location is fixed.
3) The depth of the miner is known relatively well (σ)
4) Gross location of miner for starting miner detection/ location process is given.
5) Only one miner (true signal source) is signalling.
6) The miner has an expectation/certitude of a seismic search.
7) The miner is a limited/non-ideal performer.
8) The miner has imperfect knowledge of time.
9) The miner is unimpaired.
10) The miner's source element must be readily available and reasonable.
11) The source impact area is an undeveloped, but probable feature.

THE MESSAGE TRANSMISSION PATH AND NOISE ENVIRONMENT

1) The seismic path is initially unknown.

2) The seismic path is linear and time-invariant.

3) Identification of the earth seismic path must proceed from the surface.

4) The surface will most likely be sloped.

5) The seismic noise during a rescue operation is the sum of:

    a) signal induced noise (path scatter)
    b) rescue sources
    c) basic background
    d) altered mine sources
    e) message noise
    f) system noise

THE MESSAGE DETECTION/LOCATION ACTIVITY ON THE SURFACE

1) The surface team will have a mine map and limited mine geological data.

2) The surface team has imperfect knowledge of when signals are transmitted.

3) The surface team has imperfect knowledge of when only noise is present.

4) Use of arrays and burial of seismometers are not mutually exclusive options.

5) Burial to 50 Ft. is an upper bound for the seismometer plant in alluvium.

6) Measurement will not be constrained to the vertical component.

7) The surface team knows the performance of the measuring system.

8) Deep pre-planted sensors may be available at some mines.

9) The search aspects of the problem will be tabled.

E. DESIRED END PRODUCT

AND SCHEDULE OF

PRESENT EFFORT

ARTHUR D. LITTLE, INC. - R. LAGACE

DESIRED STUDY OUTPUTS

- "BEST" ESTIMATES (Based on Present Data) OF:

  THE PROBABILITY OF DETECTION

  and

  THE ACCURACY OF LOCATION

  OF A MINER TRAPPED IN REAL EARTH.

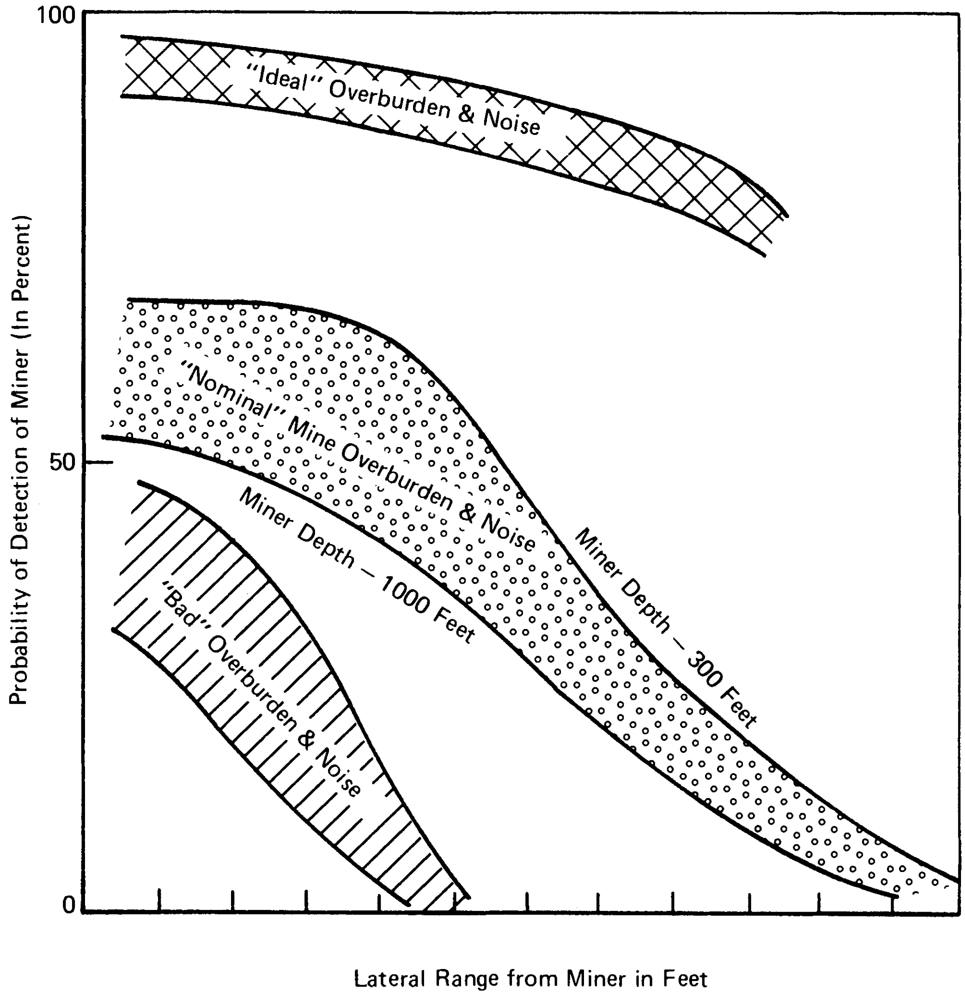
- HOW THESE ESTIMATES CHANGE WITH:

  SYSTEM COMPLEXITY AND COST

- WHAT IS STILL NEEDED IN TERMS OF:

  BASIC DATA
  ANALYSES
  EXPERIMENTS

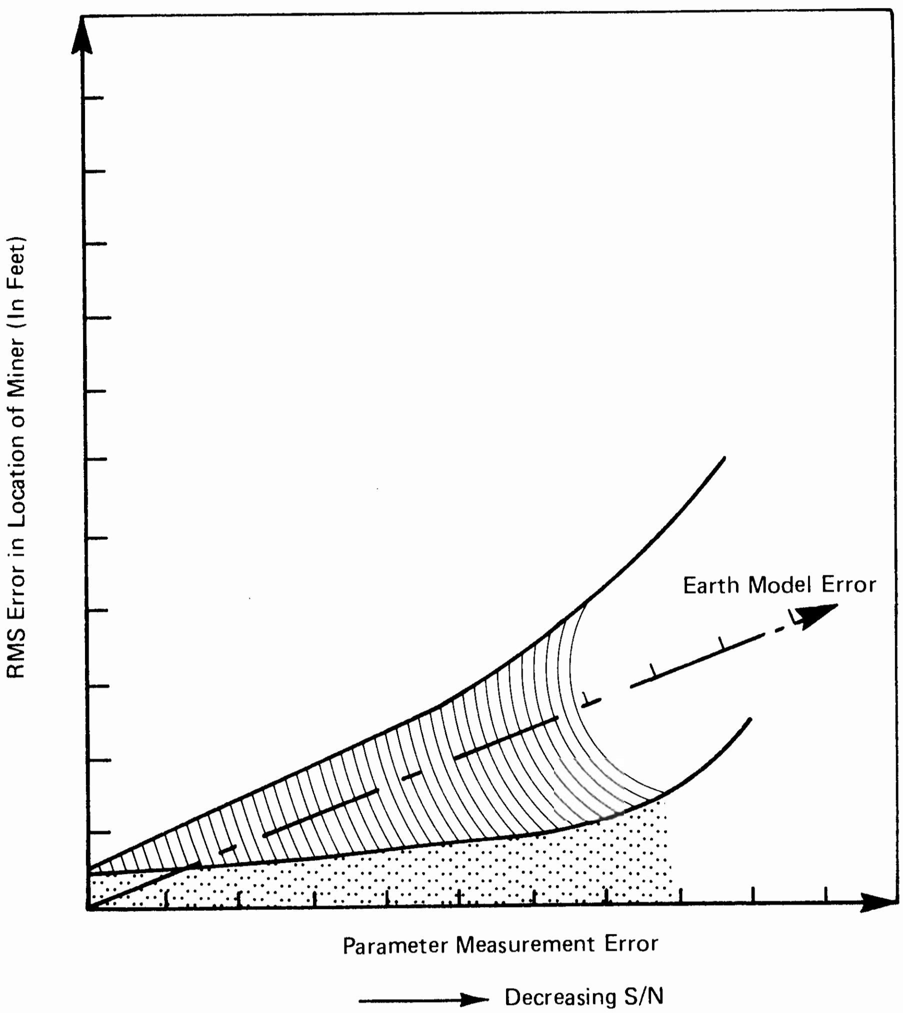
  TO IMPROVE AND/OR VERIFY THESE ESTIMATES



Conditions:

System Configuration —
Miners Source and Message —
Detection Method—

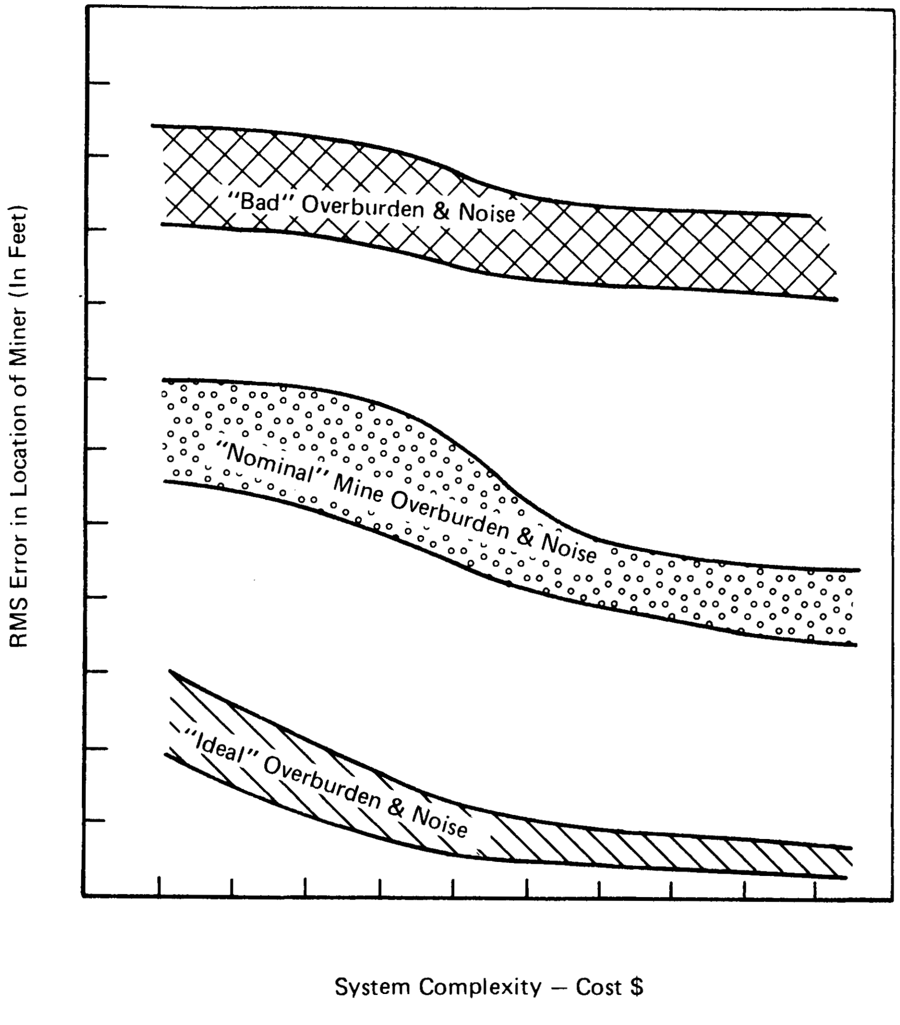
MINER DETECTION
(SAMPLE CONCEPTUAL SKETCH)



Conditions:

System Configuration —
Location Method —
Miner Depth —
Miner's Source and Message —
Overburden Transmission Characteristic —
Noise Environment —

MINER LOCATION
(SAMPLE CONCEPTUAL SKETCH)



PERFORMANCE VERSUS SYSTEM COMPLEXITY—COST (SAMPLE CONCEPTUAL SKETCH)

F. IDENTIFICATION AND DISCUSSION OF MAJOR TASKS AND TASK ASSIGNMENTS

ARTHUR D. LITTLE, INC. - R. LAGACE

WITH PARTICIPATION BY CONSULTANTS, AND BUREAU OF MINES STAFF AND ADL STAFF

CONSULTANTS:

FRANK CROWLEY	-	WESTON OBSERVATORY AND AFCRL
WILLIAM DEAN	-	TELEDYNE GEOTECH
JOHN KUO	-	COLUMBIA UNIVERSITY
ENDERS ROBINSON*	-	INDEPENDENT

BUREAU OF MINES:

HOWARD PARKINSON	-	PMSRC
JAMES POWELL	-	PMSRC

ARTHUR D. LITTLE, INC.

JOHN GINTY

ROBERT LAGACE

MARTYN ROETTER

RICHARD SPENCER

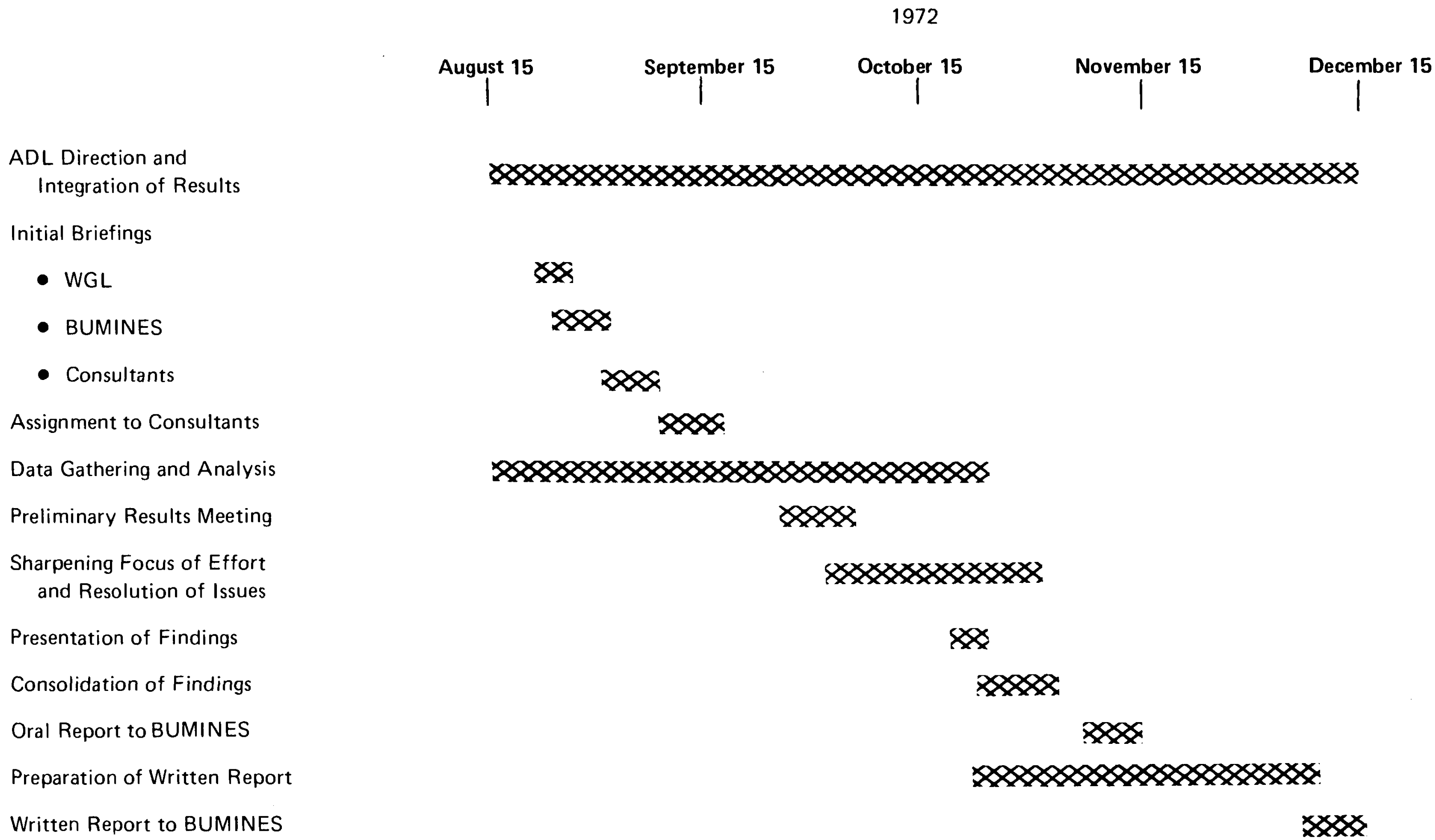
CONSULTANTS: (Who Had to Receive Individual Briefings)

ROBERT CROSSON DAVID PETERS	-	UNIVERSITY OF WASHINGTON
ROY GREENFIELD	-	PENNSYLVANIA STATE UNIVERSITY
FRANK PILOTTE	-	VELA SEISMOLOGICAL CENTER

* Could not participate as originally intended because of scheduling conflicts with prior commitments.

T A S K S

	OUTPUTS / INPUTS	DETECTION	PARAMETER ESTIMATION	LOCATION	FIELD UTILIZATION
"F I X E D"	SOURCES Fn of: Type : Man : Impact Area : Tunnel	• Strength • Directional and Coherence Charac. • Pulse Shape • Rep. Rate		• Directional Charac.	
"F I X E D"	TRANS. MEDIUM. CHARAC. Fn of: Layers (Type, Thick, Angle, etc.)	• Attenuation • Signal Modification - Freq. Response - Time Domain - Spatial Coh.		• Earth Model (Detailed)	
"F I X E D"	NOISE Fn of: Sources - Sig. Induced - Rescue Sources - Basic Bgrd. - Altered Mine - Message - System	• Spectrum Levels • Time Charac. i.e. Stationarity Impulsiveness • Spatial Coherence		• Noise Weighting of Parameters	
"V A R I A B L E"	SENSORS Fn of: Depth : Coupling	• Sensitivity • Array Gain/ Directionality • Dynamic Range • Polarization	✦ Sensitivity ✦ Array Gain/ Directionality ✦ Dynamic Range ✦ Polarization	• Array Geometry and Location	
"V A R I A B L E"	SIGNAL PROCESSING	• Candidate • Detection Methods	• Candidate • Estimation Methods		
"V A R I A B L E"	DATA PROCESSING AND COMPUTATION			• Location Algorithms • Mine Maps	



PROGRAM SCHEDULE

III. ORAL PRESENTATION OF STUDY RESULTS TO

PITTSBURGH MINING SAFETY AND RESEARCH CENTER

NOVEMBER 21, 1972

SEISMIC LOCATION OF ISOLATED MINERS

Arthur D. Little, Inc.

(Copies of Flip Charts and Viewgraphs)

A. OVERVIEW AND SUMMARY OF PRINCIPAL FINDINGS

ROBERT L. LAGACE

OBJECTIVE OF STUDY

IDENTIFY:

WHAT CAN BE DONE

AND

HOW WELL

BY SEISMIC MEANS

TO:

- DETECT A MINER
- LOCATE A MINER

TO WITHIN: A SECTION

: AN ENTRY WIDTH

SEISMIC LOCATION SYSTEM:

GENERAL GROUND RULES

- Hardware: Field Suitable and Rapidly Deployable
- System Constrained to Present State-of-Art Techniques and Hardware
- System Operation From Surface
- System Self-Contained in its Operation and Calibration
- System Capable of Producing Timely Location Estimates
- System Operation Compatible with and Complementary to Overall Rescue Effort
- Signal Sources Readily Available and Reasonable - No Special, Carried Devices
- No Wide-Area Search - - Likely Areas Given
- Team Will Have Benefit of Mine Maps

DESIRED STUDY OUTPUTS

- "BEST" ESTIMATES (Based on Present Data) OF:

  THE PROBABILITY OF DETECTION

  and

  THE ACCURACY OF LOCATION

  OF A MINER TRAPPED IN REAL EARTH.

- HOW THESE ESTIMATES CHANGE WITH:

  SYSTEM COMPLEXITY AND COST

- WHAT IS STILL NEEDED IN TERMS OF:

  BASIC DATA
  ANALYSES
  EXPERIMENTS

  TO IMPROVE AND/OR VERIFY THESE ESTIMATES

DETECTION OF A MINER

RANGES

ON THE ORDER OF

1000 FEET

CAN BE ACHIEVED

SUBJECT TO THE CONTROL OF

MANMADE NOISE SOURCES*

This Should Allow More

Than Adequate Coverage

of Typical Mine Sections

* Namely, surface operations and activity over and in the vicinity of the detection area must be severely restricted and possibly prohibited.

LOCATION OF A MINER

TO WITHIN A SECTION

LOCATION ACCURACIES
TO WITHIN
100 FEET
TO DEPTHS OF 1000 FEET
APPEAR ATTAINABLE

SUBJECT TO:

- CONTROL OF MANMADE NOISE SOURCES*
- AN ADEQUATE SEISMIC REPRESENTATION OF THE EARTH

* Namely, surface operations and activity over and in the vicinity of the location area must be severely restricted and possibly prohibited. Signal-to-noise ratios in excess of that for detection will also be required.

LOCATION OF A MINER

TO WITHIN AN ENTRY WIDTH

APPEARS TO BE AN UNREALISTIC GOAL

HOWEVER: UNDER VERY FAVORABLE CIRCUMSTANCES*

ACCURACIES OF ABOUT 30 FEET APPEAR ATTAINABLE

With the Aid of An Accurate Mine Map - This Should Allow Identification

Of the Entry in Which the Miner is Located

* For manmade noise, same comments as for previous chart. An even more accurate representation of the earth, or a shallower depth (300 feet or less), will also be necessary.

EXPECTED IMPACT OF INVESTMENTS ON PERFORMANCE AND COST

IMPACT OF ↓ ON →	Improving Overall Performance	Increasing Overall Cost
Truly Fieldable Hardware	HIGH	LOW
Trained Experienced Field Crews	HIGH	MODERATE
Site Pre-Calibration Preparation	HIGH	HIGH
Improved Seismic Earth Models	HIGH	LOW
Conventional S/N Enhancement Methods	HIGH	LOW
Sophisticated S/N Enhancement Methods	LOW	HIGH
Controlling Site Manmade Noise	HIGH	LOW

TO IMPROVE AND/OR VERIFY PERFORMANCE ESTIMATES

NEED

BETTER QUANTITATIVE
CHARACTERIZATION OF:

- SEISMIC SIGNALS FROM SOURCES AVAILABLE TO MINERS
- SEISMIC NOISE IN COAL MINE REGIONS
- SEISMIC PROPAGATION ATTRIBUTES OF COAL MINE OVERBURDENS

B. PROBLEM

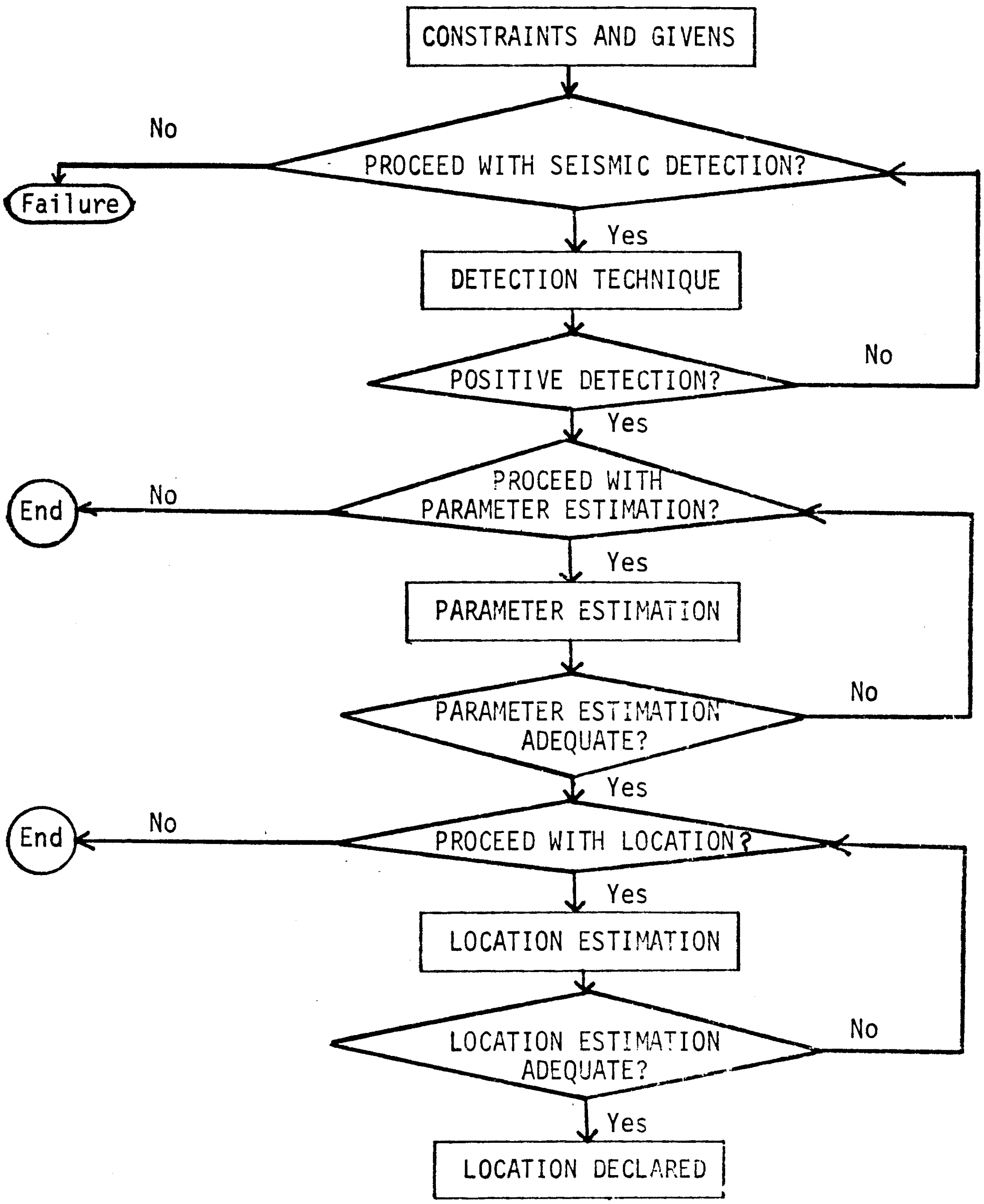
FORMULATION

AND

TASKS

ROBERT L. LAGACE

FORMULATION OF PROBLEM



TASKS

	OUTPUTS / INPUTS	DETECTION	PARAMETER ESTIMATION	LOCATION	FIELD UTILIZATION
"FIXED"	SOURCES Fn of: Type : Man : Impact Area : Tunnel	• Strength • Directional and Coherence Charac. • Pulse Shape • Rep. Rate		• Directional Charac.	
	TRANS. MEDIUM. CHARAC. Fn of: Layers (Type, Thick, Angle, etc.)	• Attenuation • Signal Modification - Freq. Response - Time Domain - Spatial Coh.		• Earth Model (Detailed)	
	NOISE Fn of: Sources - Sig. Induced - Rescue Sources - Basic Bgrd. - Altered Mine - Message - System	• Spectrum Levels • Time Charac. i.e. Stationarity Impulsiveness • Spatial Coherence		• Noise Weighting of Parameters	
"VARIABLE"	SENSORS Fn of: Depth : Coupling	• Sensitivity • Array Gain/ Directionality • Dynamic Range • Polarization	✦ Sensitivity ✦ Array Gain/ Directionality ✦ Dynamic Range ✦ Polarization	• Array Geometry and Location	
	SIGNAL PROCESSING	• Candidate • Detection Methods	• Candidate • Estimation Methods		
	DATA PROCESSING AND COMPUTATION			• Location Algorithms • Mine Maps	

C. DETECTION OF AN ISOLATED MINER

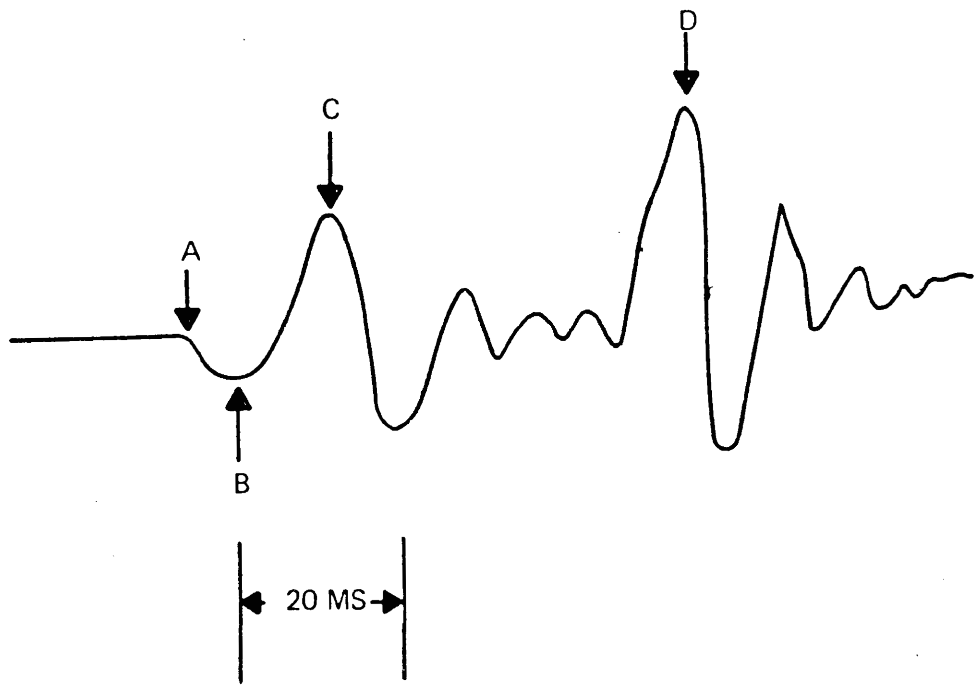
ROBERT L. LAGACE

DETECTION OF A MINER

CONSIDERATIONS FOR
ESTIMATING DETECTION RANGES

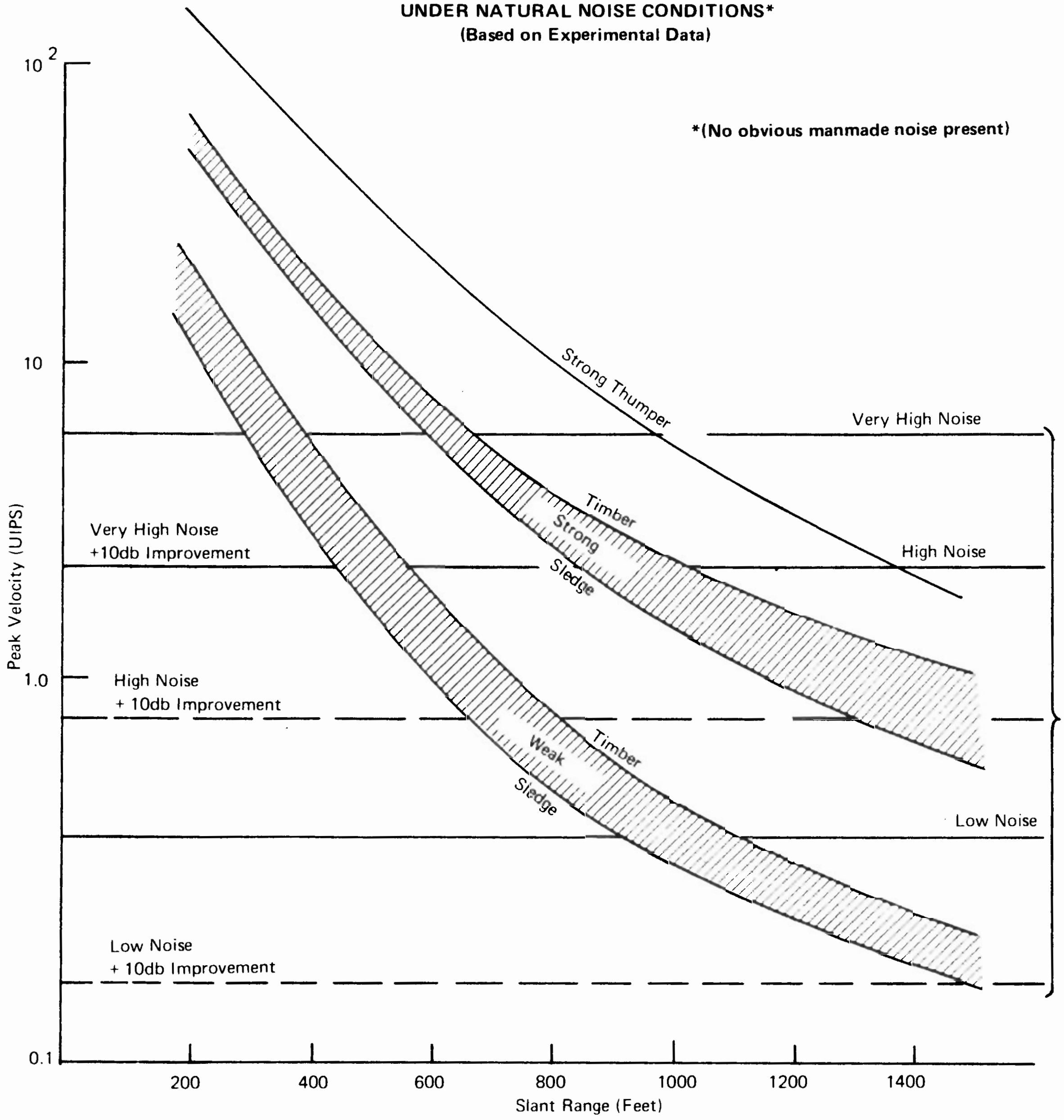
- SIGNAL STRENGTH
  - Source
  - Transmission Loss
- NOISE LEVELS
  - Natural Background
  - Manmade Sources
- SIGNAL-TO-NOISE
  ENHANCEMENT METHODS
- RANGE ESTIMATION
  - Detection Criteria

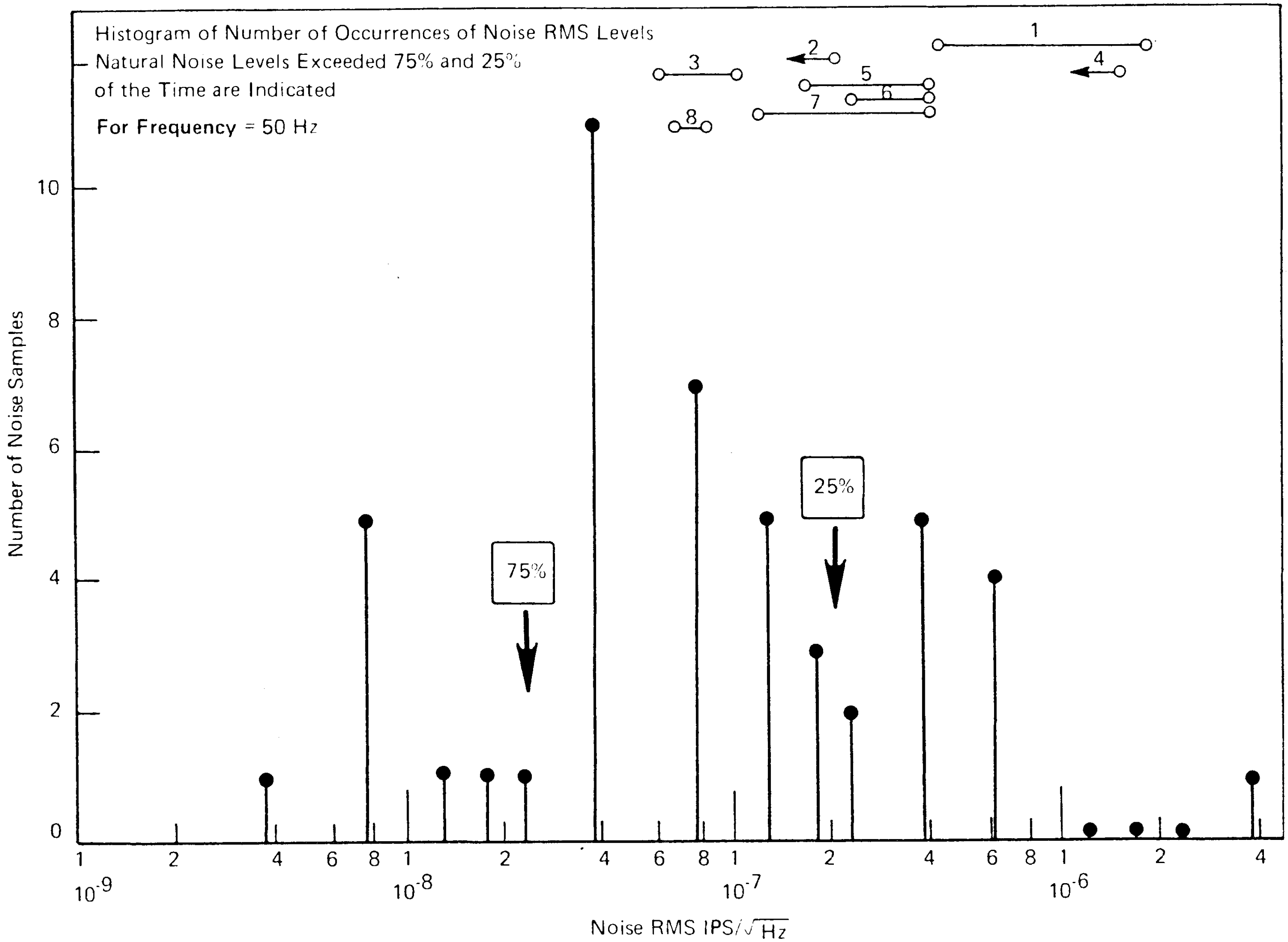
SCHEMATIC GENERALIZED SEISMIC SIGNAL
(Applicable to Mine Data Obtained to Date)



COMPOSITE PLOT FOR ESTIMATING DETECTION RANGES UNDER NATURAL NOISE CONDITIONS*

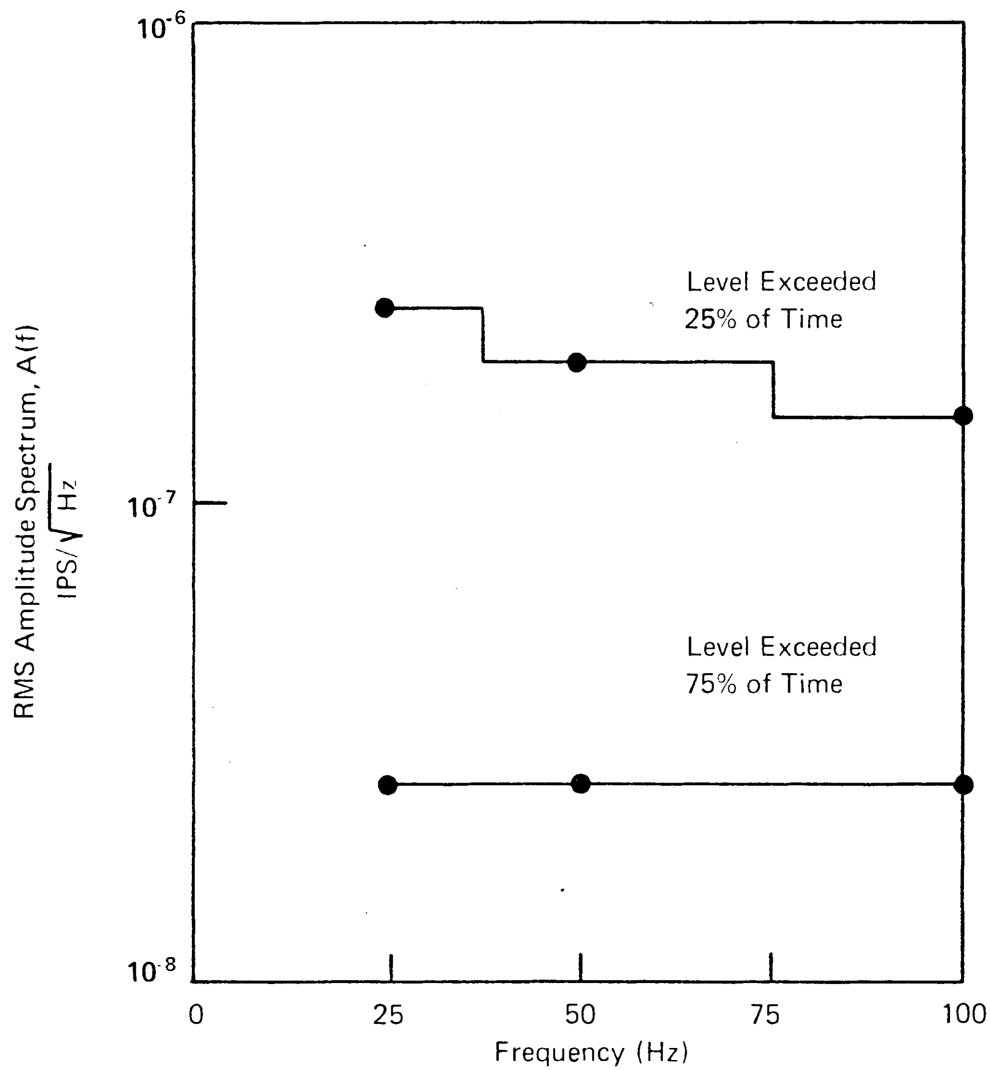
(Based on Experimental Data)



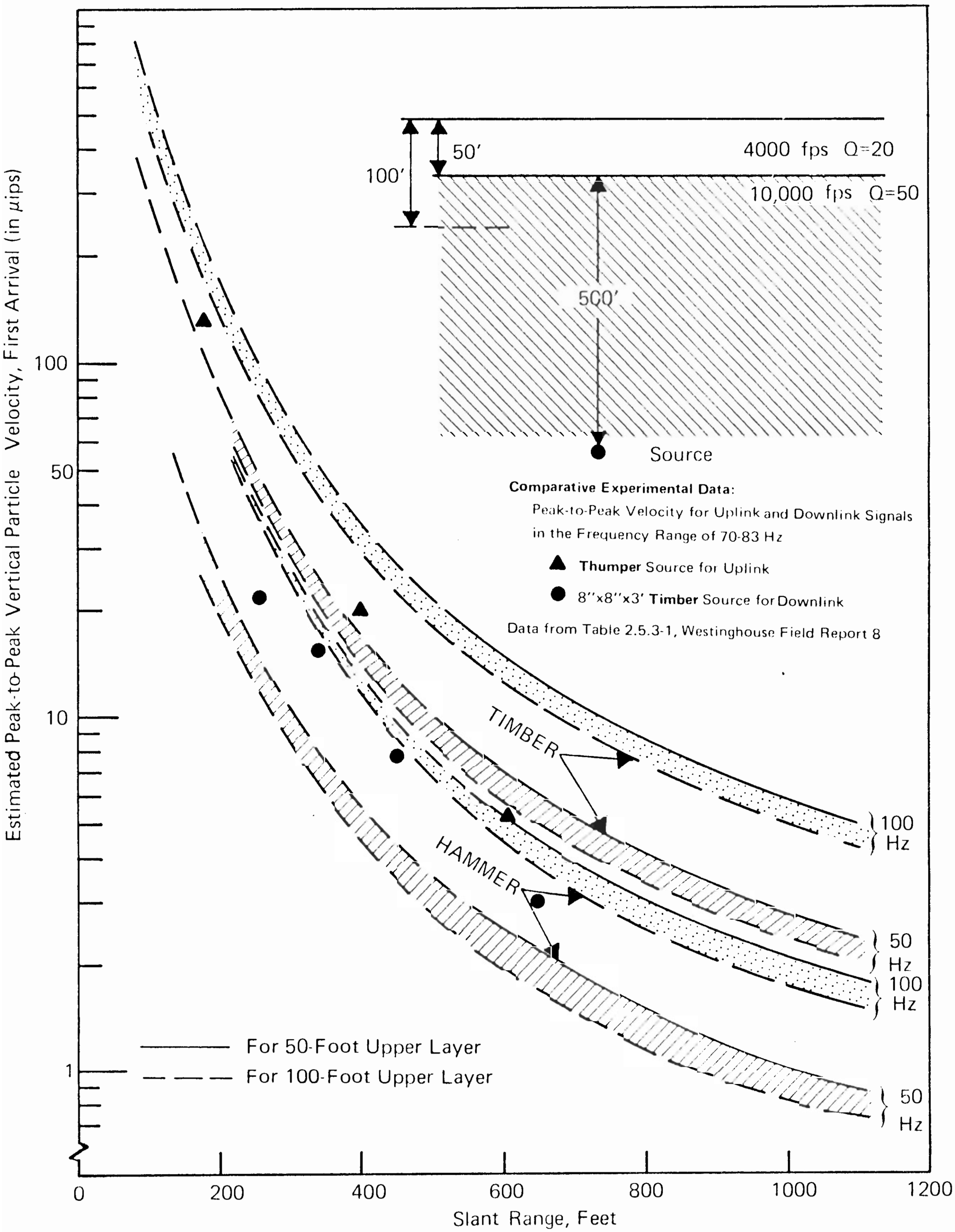


Westinghouse data for individual mines are included for comparison, and maximum and minimum noise levels are shown as open circles connected by lines. Ignore the vertical axis in relation to these data. Arrows pointing to the left indicate that system noise limited noise estimates for low noise periods. The Westinghouse data are taken from the Westinghouse Report Table 2-4. The order of the mines, going from the top of the figure to the bottom data points, corresponds to the field report numbers for the mines.

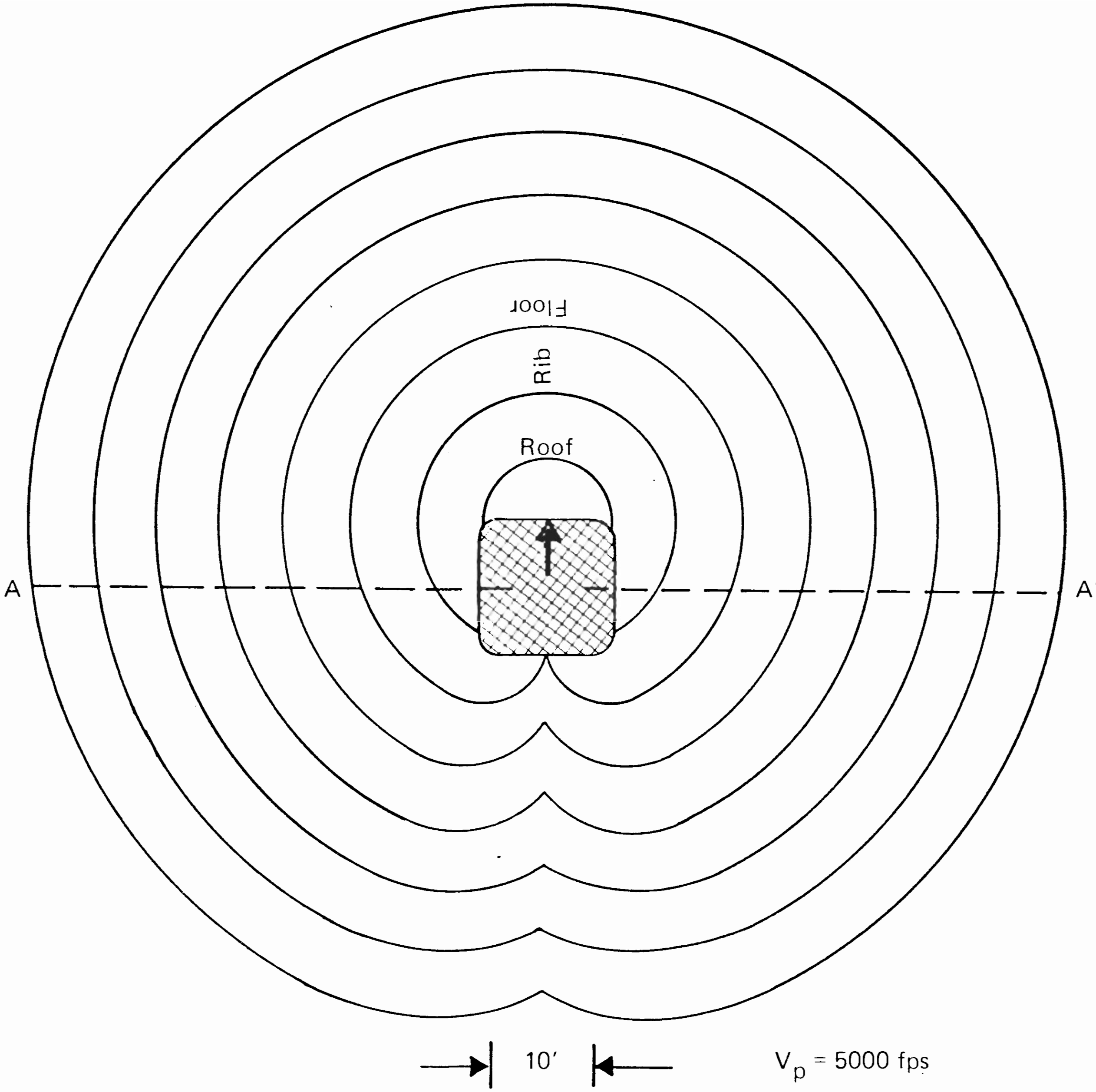
NATURAL SEISMIC NOISE LEVELS: BASED ON FRANTTI DATA WHEN NO MAN-MADE NOISE IS PRESENT



NATURAL SEISMIC NOISE LEVELS BASED ON FRANTTI DATA WHEN NO OBVIOUS MAN-MADE NOISE IS PRESENT (RMS AMPLITUDE SPECTRA)



ESTIMATED PEAK-TO-PEAK VERTICAL PARTICLE
VELOCITY FOR THE FIRST P-WAVE ARRIVAL
(BASED ON THEORETICAL CONSIDERATIONS)



DISTORTED WAVE FRONTS OF A VERTICAL SECTION A-A′

SIGNAL-TO-NOISE IMPROVEMENT

METHODS

FOR DETECTION

Most Useful

- BANDPASS FILTERING
- BURIAL OF SENSORS
- SUBARRAYS
  - Size Adjust
  - Delayed or Direct Sum
  - Weighted Sum

FOR ARRIVAL TIME ESTIMATION

Most Useful

- SAME AS ABOVE
- SUMMING (STACKING) OF REPEATED SIGNALS

FOR DETECTION AND ARRIVAL TIME ESTIMATION

Least Useful

- REMODE
- LINEAR PHASE FILTERING OF MULTICOMPONENT DATA
- MATCHED FILTERING
- MULTI-CHANNEL MAXIMUM LIKELIHOOD ARRAY PROCESSING
- MULTICHANNEL WIENER FILTERING
- SINGLE AND MULTICHANNEL PREDICTION ERROR FILTERING

MAXIMUM SLANT RANGES (In Feet) FOR DETECTION-UNDER NATURAL NOISE CONDITIONS**

Source	Low Noise		High Noise		Very High Noise	
	W/O-S/N I*	W-S/N I	W/O-S/N I	W-S/N I	W/O S/N I	W-S/N I
Strong Thumper	>2000	>2000	1400	>2000	950	1400
Strong						
Timber	>2000	>2000	1050	>1500	650	1050
Sledge	>1500	>2000	900	1250	550	900
Weak						
Timber	1100	>1500	550	800	375	550
Sledge	900	>1400	450	625	300	450

* W/O - S/N I = Without 10dB Signal-to-Noise Improvement
W - S/N I = With 10dB Signal-to-Noise Improvement

** No obvious manmade noise sources

SEPARATION GUIDELINES FOR DEALING WITH MAN-MADE NOISE SOURCES*

Type	Distance	Detector
Light Vehicular	10,000 ft.	Single Phone
	5,000 ft.	Buried Array
Piston Aircraft	20,000 ft.	Single Phone
	5,000 ft.	Buried Array
Lone Trees and Telephone Poles	400 ft.	Single Phone
(heavy wind condition)	150 ft	Buried Array
Drilling	7,500 ft.	Single Phone
	5,000 ft.	Buried Array
Man Walking	1,000 ft.	Single Phone
	500 ft.	Buried Array
Machinery (heavy)	10,000 ft.	Single Phone
	2,000 ft.	Coherent Processing
Intra-Mine Sources	3,000 ft.	Single Phone
(miner equivalent)	3,000 ft.	Buried Array

* The detector scheme and noise source-detector separation distances shown are those which should be sufficient to keep the disturbance of the associated noise source within the "base" noise levels discussed in Part Nine. These guidelines should be considered both speculative and conservative.

D. LOCATION OF AN ISOLATED MINER

ARRIVAL TIME ESTIMATES AND LOCATION ACCURACIES USING SURFACE ARRAYS AND EARTH MODELS

MARTYN F. ROETTER

LOCATION ACCURACIES USING REFERENCE EVENT METHOD

RICHARD H. SPENCER

MINER LOCATION

CONSIDERATIONS IN THE ESTIMATION

OF

LOCATION ACCURACIES

ARRIVAL TIME ESTIMATES

- Enhancement of Arrival Time Accuracies

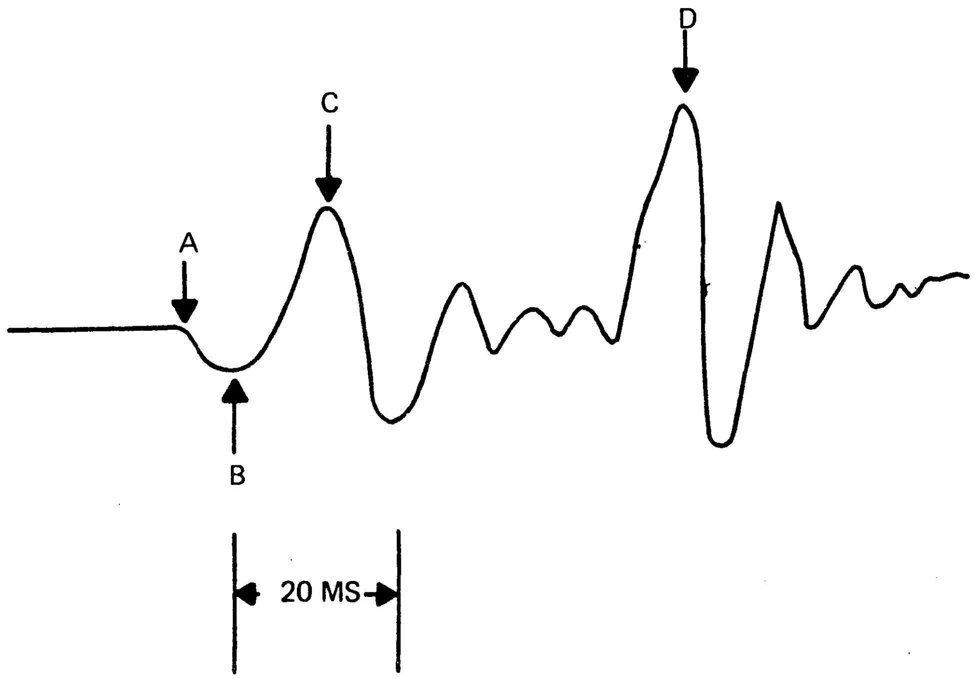
TREATMENT OF THE EARTH

- Model Representation Based on
  - General Geological Knowledge
  - Refraction Survey Data
- "Black Box" Approach with Travel Times Based on Reference Events

1. ARRIVAL TIME ESTIMATES

MARTYN F. ROETTER

SCHEMATIC GENERALIZED SEISMIC SIGNAL
(Applicable to Mine Data Obtained to Date)

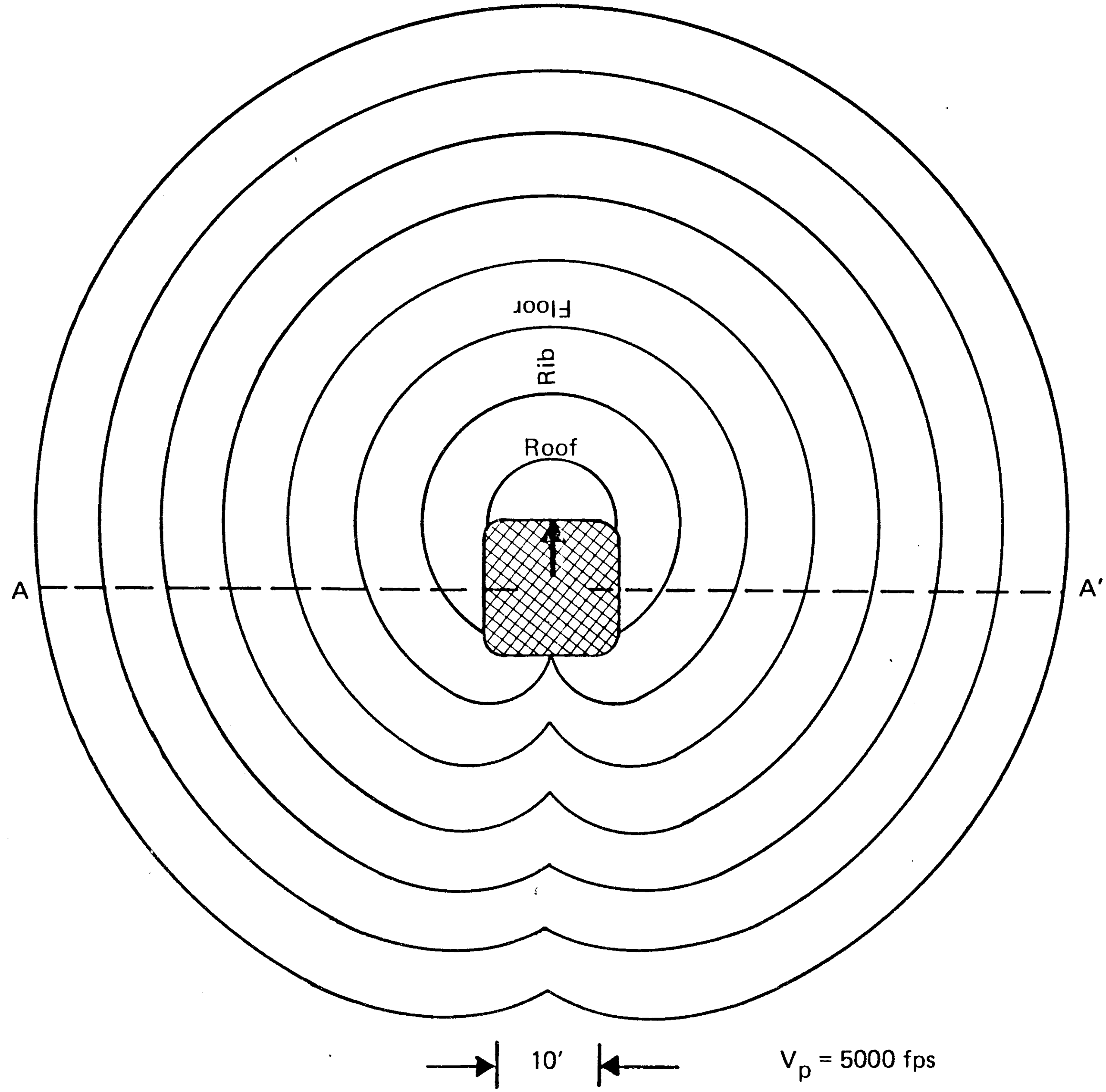


ACCURACY OF ARRIVAL TIMES

SIGNAL ASSUMED TO LIE IN RANGE 50-100 Hz

- $\sim$ 1 ms. ACCURACY IF PEAK OF FIRST ARRIVAL RECOGNIZED
- $\sim$ 5-10 ms. ACCURACY IF PEAK OF A LATER ARRIVAL CHOSEN
- $\sim$ 50 ms. ACCURACY IF SEVERAL CYCLES OF SIGNAL MISSED

DISTORTED WAVE FRONTS OF A VERTICAL SECTION A - A'



2. LOCATION ACCURACIES USING SURFACE ARRAYS AND EARTH MODELS

MARTYN F. ROETTER

COAL MINE GEOLOGY

GENERAL CHARACTERISTICS OF EASTERN U.S.
BITUMINOUS COAL MINE ENVIRONMENTS:

- Geologic Strata Usually Horizontal (a Slope of 1 in 50 is Large)
- Strata Often Pinch Out or Grade Into Different Types
- Geologic Sections Tend to Remain Similar Over Distances of 1-3 Miles, But Can Change Considerably Over 10 Miles
- Little Faulting Found in Pa. or Northern W. Va. - Faulting More Common in Southern Areas (Western Ky.)
- Seismic Velocities in Overburden Can Vary From 14000 fps to 500 fps, Generally Tending to Increase With Depth
- The Thickness of the Upper Weathered Layer Can Vary Significantly From One Geophone Subarray to Another

ACCURACY OF EARTH MODELS

ASSUMPTION: The Earth Can Be Represented by a Set of Laterally Homogeneous, Horizontal Layers With Different Seismic Velocities.

THEN: Refraction Surveys Allow The Thicknesses and Velocities of These Layers to be Determined to Within About 5%.

The Errors May be Somewhat Less for the Upper and Lower Layers, and Greater for the Middle Layers.

<u>ACHIEVABLE LOCATION ACCURACY</u>*- I

- LATERAL LOCATION ACCURACIES TO <u>WITHIN ABOUT 100 FEET</u> APPEAR ACHIEVABLE IN MANY SITUATIONS

- UNDER VERY FAVORABLE CIRCUMSTANCES, ACCURACIES <u>AROUND 30 FEET</u> MAY BE ATTAINABLE

* Based on the Crosson and Peters error analysis applied to the location technique of non-linear least squares iterative inversion.

ACHIEVABLE LOCATION ACCURACY*- II

- KNOWLEDGE OF DEPTH IMPROVES LATERAL LOCATION ACCURACIES WHEN THE SEISMIC VELOCITY IS DEPTH DEPENDENT

- EARTH MODEL ERRORS OF 5% ARE MORE SERIOUS SOURCES OF INACCURACY THAN ARRIVAL TIME ERRORS OF 1-5 ms.

BUT

- ARRIVAL TIME ERRORS OF 15-20 ms. DOMINATE EARTH MODEL ERRORS OF 5%

* Ibid

ACHIEVABLE LOCATION ACCURACY*- III

- LOCATION ACCURACY INSIDE AN ARRAY IS NOT A STRONG FUNCTION OF THE ARRAY'S SIZE OR CONFIGURATION

- LOCATION ACCURACY FALLS OFF RAPIDLY OUTSIDE THE ARRAY
  - THE RATE IS SIGNIFICANTLY DEPENDENT UPON THE ARRAY GEOMETRY

---
* Ibid

ACHIEVABLE LOCATION ACCURACY*- IV

- BETTER LOCATION ACCURACY, ESPECIALLY WITH RESPECT TO DEPTH, IS ATTAINABLE IN AN EARTH WHERE THE VELOCITY IS DEPTH DEPENDENT, RATHER THAN CONSTANT

- LINEAR VELOCITY MODELS ($V = A + BZ$) ARE EXCELLENT APPROXIMATIONS TO A HORIZONTALLY LAYERED EARTH

* Ibid

CONCLUSIONS ON LOCATION ACCURACY

THESE CONCLUSIONS ARE SUBJECT TO THE FOLLOWING CONDITIONS:

- ARRIVAL TIMES CAN BE MEASURED TO WITHIN 1-5 ms.
- MODELS OF THE EARTH CAN BE APPLIED WHICH ARE "ACCURATE" TO WITHIN 5%

EARTH MODEL ACCURACY

MODEL "ACCURACY" IS A FUNCTION OF THE:

1. SEISMIC SURVEY DATA AND ANALYSIS

2. VALIDITY OF THE REPRESENTATION OF THE COMPLEX STRUCTURE OF THE ACTUAL EARTH BY A SIMPLE MODEL FOR TRAVEL TIME COMPUTATIONS

Summary of Error Diagrams†

Run #	Array Type	Station Spacing, ft.	Velocity Model	Parameter Error σ_v(%)	σ_t(sec.)	Depth Fixed?
1	Hex	600	Con	0	.001	
2	Hex	600	Lin	0	.001	
→ 3	Hex	600	Lin	5%	.001	
→ 4	Hex	600	Lin	5%	.001	*
5	Hex	1200	Con	0	.001	
6	Hex	1200	Lin	0	.001	
7	Hex	1200	Lin	5%	.001	
→ 8	Hex	1200	Lin	5%	.001	*
9	Hex	600	Con	0	.005	
→ 10	Hex	600	Lin	5%	.005	
→ 11	H	600	Lin	5%	.001	
12	Hex	600	Con	5%	.001	
→ 13	Mod Hex	450	Lin	5%	.001	
→ 14	Hex	600	2 Lay	5%	.001	
15	H	600	2 Lay	5%	.001	
→ 16	Hex	600	2 Lay	5%	.001	*
17	Hex	600	2 Lay	5%	.005	*
→ 18	Hex	600	4 Lay	5%	.001	*
→ 19	Hex	600	4 Lay	5%	.005	*
→ 20	H	600	Lin	5%	.001	*
21	Hex	600	Lin	5%	.010	*
22	Hex	600	Lin	5%	.015	*
→ 23	Hex	600	Lin	5%	.020	*
24	Hex	600	Lin	1%	.005	*

† Ibid

* indicates depth fixed for error computations.

† Arrows indicate the error diagrams shown in the presentation. They can be found in Part Three.

FURTHER RESOLUTION OF THE QUESTION OF ACHIEVABLE LOCATION ACCURACY

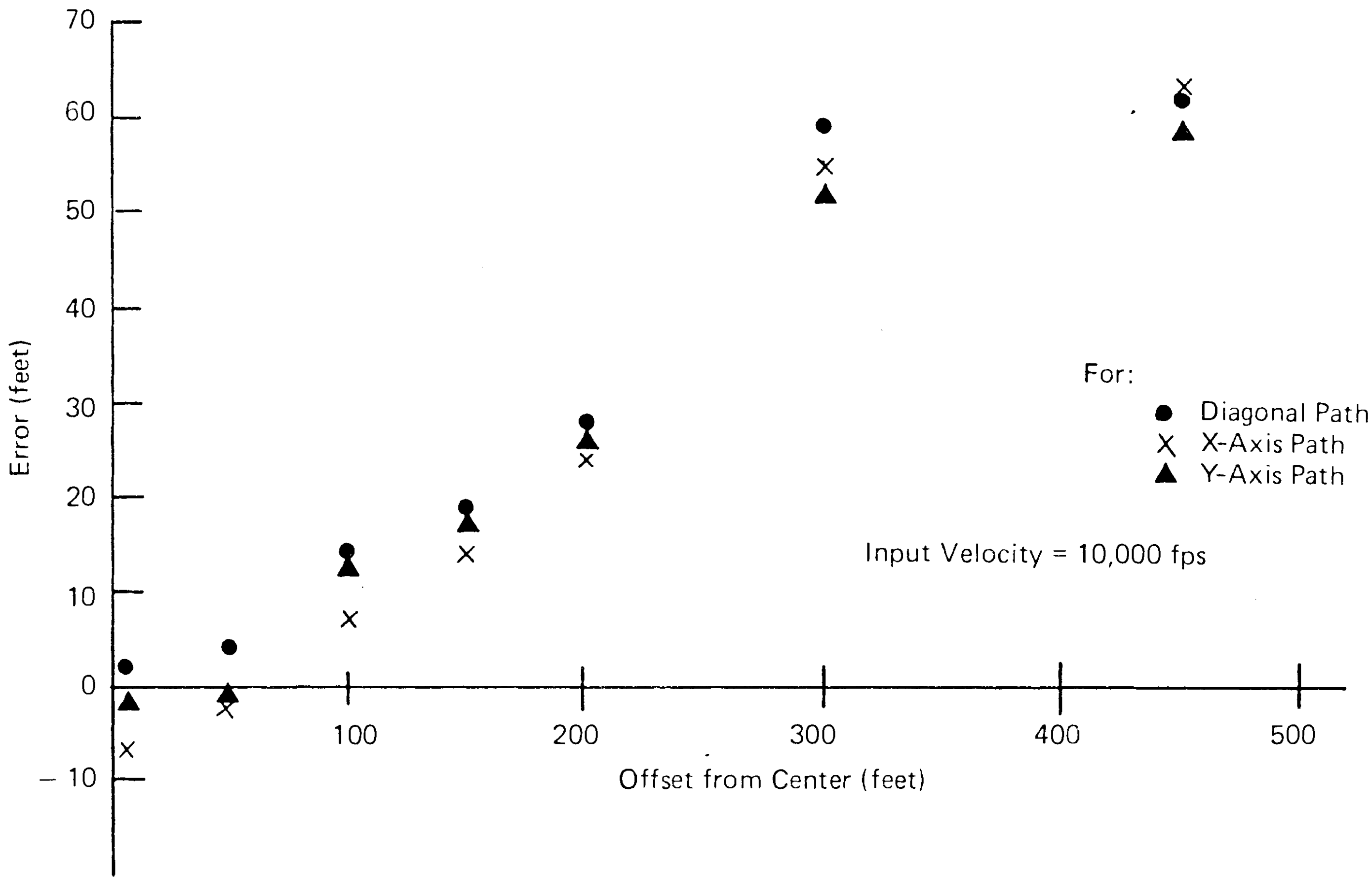
MAJOR PROGRAM COMPONENTS:

- COMPREHENSIVE SEISMIC SURVEY OF REPRESENTATIVE MINE SITE(S) BY EXPERIENCED PERSONNEL

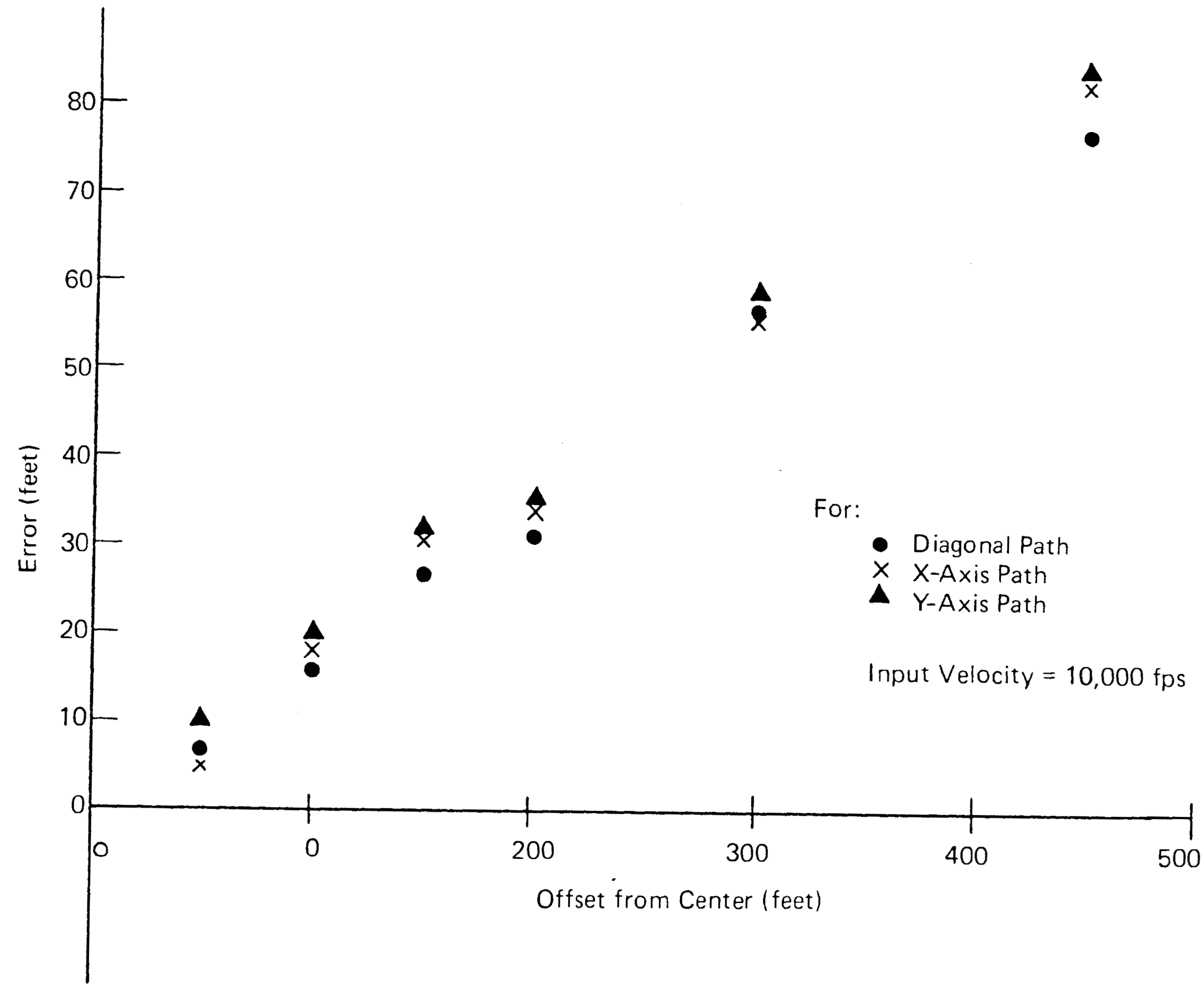
- CONTROLLED (STRONG SOURCE) LOCATION EXPERIMENTS USING:

  1. Actual Measured earth velocity profile

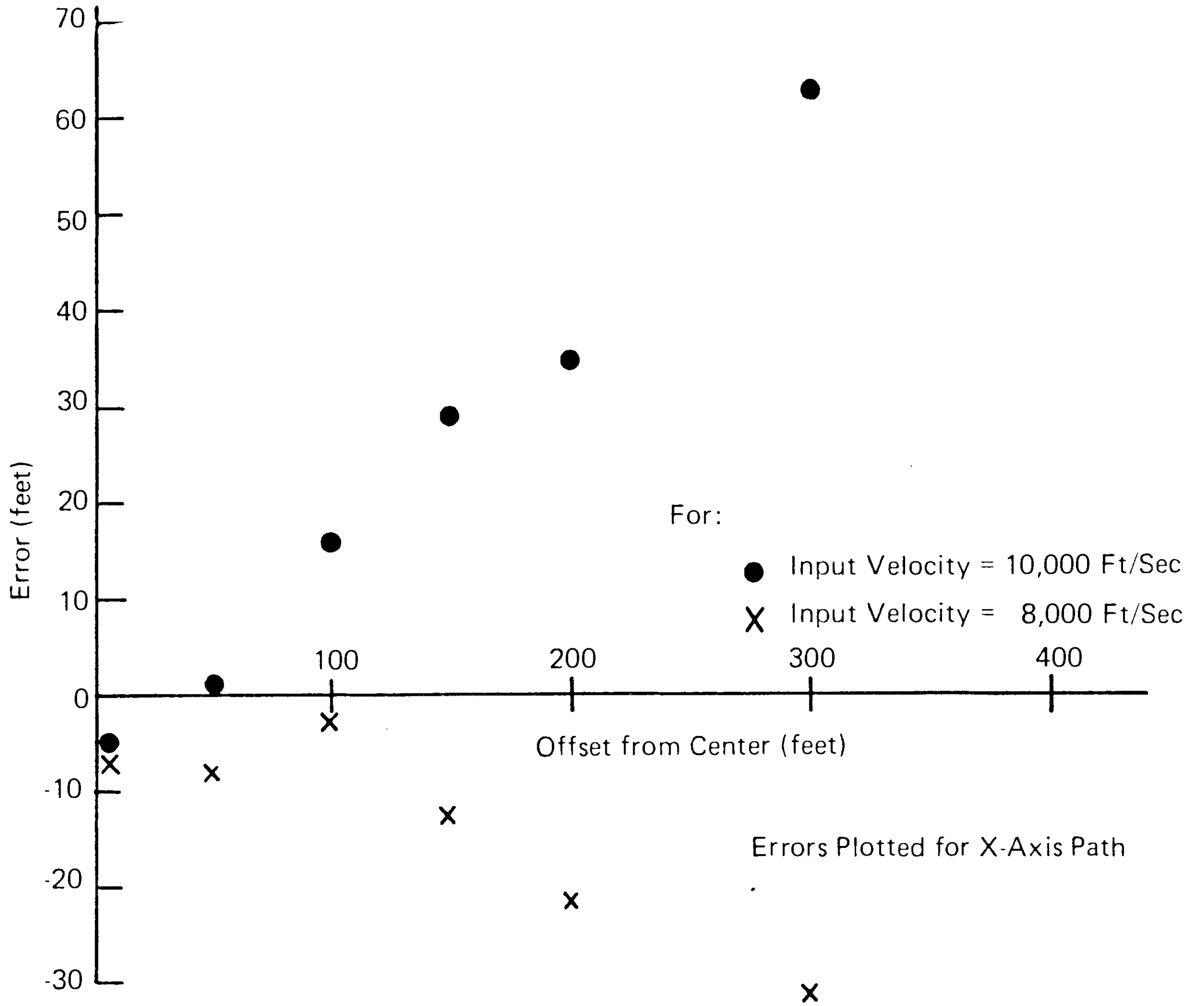
  2. Simple Model Approximations to 1.



"MINER" LOCATION ERROR
300 FOOT DOUBLE SQUARE



"MINER" LOCATION ERROR
400 FOOT HEXAGON



"MINER" LOCATION ERROR
150 FOOT DOUBLE SQUARE

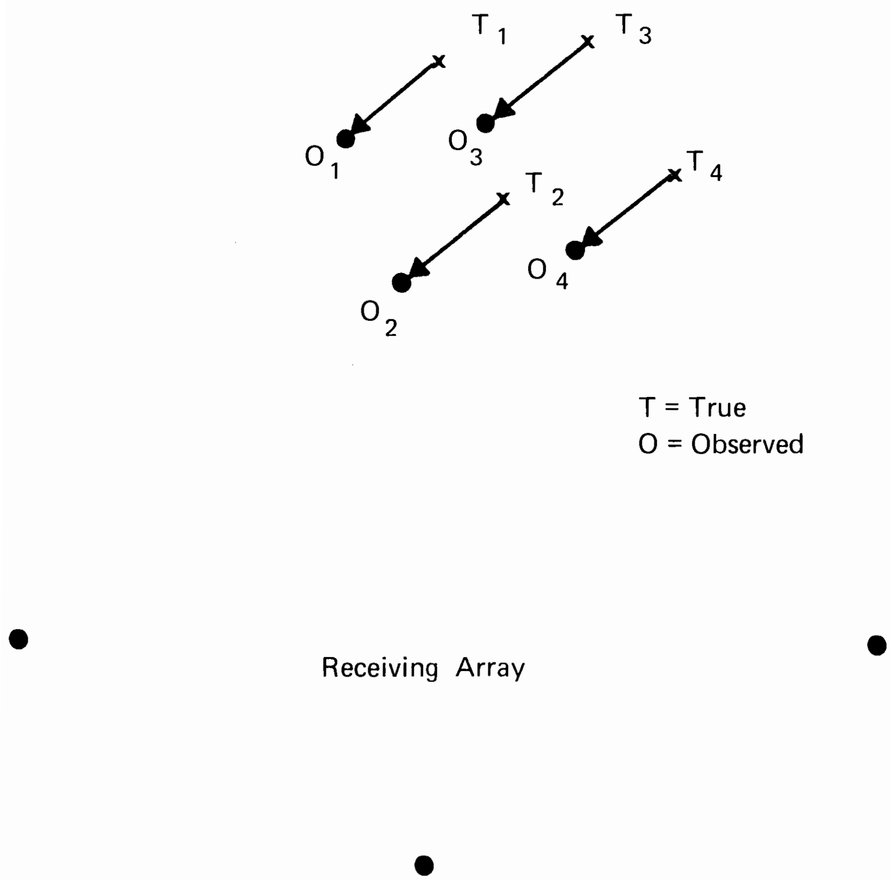
3. LOCATION ACCURACIES

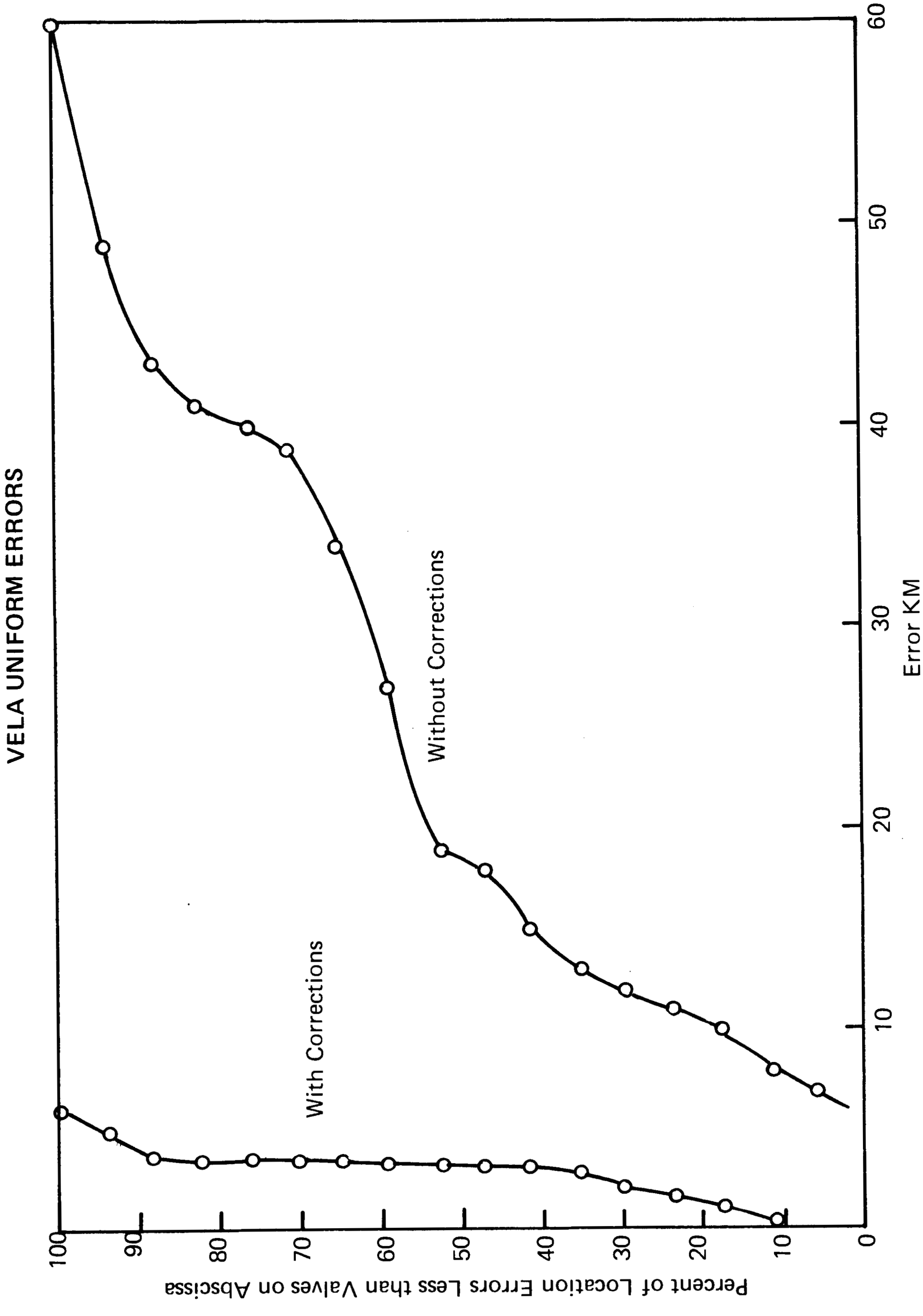
USING

REFERENCE EVENT METHOD

RICHARD H. SPENCER

REFERENCE EVENT




VELA UNIFORM ERRORS
With Corrections
Without Corrections
Error KM
0
10
20
30
40
50
60
70
80
90
100
Percent of Location Errors Less than Valves on Abscissa

REFERENCE EVENT

EXPERIMENT

OBJECTIVE: TO DETERMINE ACCURACY AND NUMBER OF CALIBRATION EVENTS REQUIRED

- 10-15 Geophones
- Two or More Sources (Timber, Hammer, Explosives)
- Source Locations - 25' to 50' Grid Running Over 1,000 ft.
  - Accurately Known Locations
  - Time Mark Desired
- Aperture Control
- Must Try in Several Mines

TO BE DONE BY SKILLED GEOPHYSICAL SERVICE COMPANY

DETAILED TEST PLAN TO BE DEVELOPED

E. SEISMIC SYSTEM FIELDABILITY AND INSTRUMENTATION

RICHARD H. SPENCER

F I E L D A B I L I T Y

GIVEN:

- LOCATION REQUIRES CALIBRATED SIGNALS
- POWER MAY NOT BE AVAILABLE
- TEST AND REPAIR FACILITIES NOT READILY AVAILABLE
- QUICK RESPONSE UNDER EMERGENCY CONDITIONS REQUIRED
- OPERATING PERSONNEL MUST BE EXPERIENCED - MUST KNOW EQUIPMENT AND ITS CAPABILITIES

HARDWARE:

- VERTICAL SEISMOMETER - AMPLIFIER ABLE TO BE BURIED
- 12-CHANNEL TAPE RECORDER
- ACCURATE, RECOVERABLE TIME CODES ON TAPE
- CONTINUOUS TIME REFERENCE ON TAPE
- SEISMOMETER CALIBRATION DEVICE
- VARIABLE FILTERING - GAIN
- COMPACT LIGHT WEIGHT RUGGED MODULAR SIMPLE
- PROVEN HARDWARE
- SELECTABLE TIME BASE DISPLAYS
- PROCESSING CENTER
- BATTERY OPERATION
- WATER PROOF NON-AMBIGUOUS CABLING
- TOOLS
- RADIO COMMUNICATION FOR CREW

PERSONNEL:

- 3-MAN CREW (MINIMUM)
  - OPERATOR/ANALYST - TEST CHIEF-GEOPHYSICAL ENGINEER
  - ELECTRICAL TECHNICIAN
  - FIELD TECHNICIAN
  - ON SITE ADDITIONS

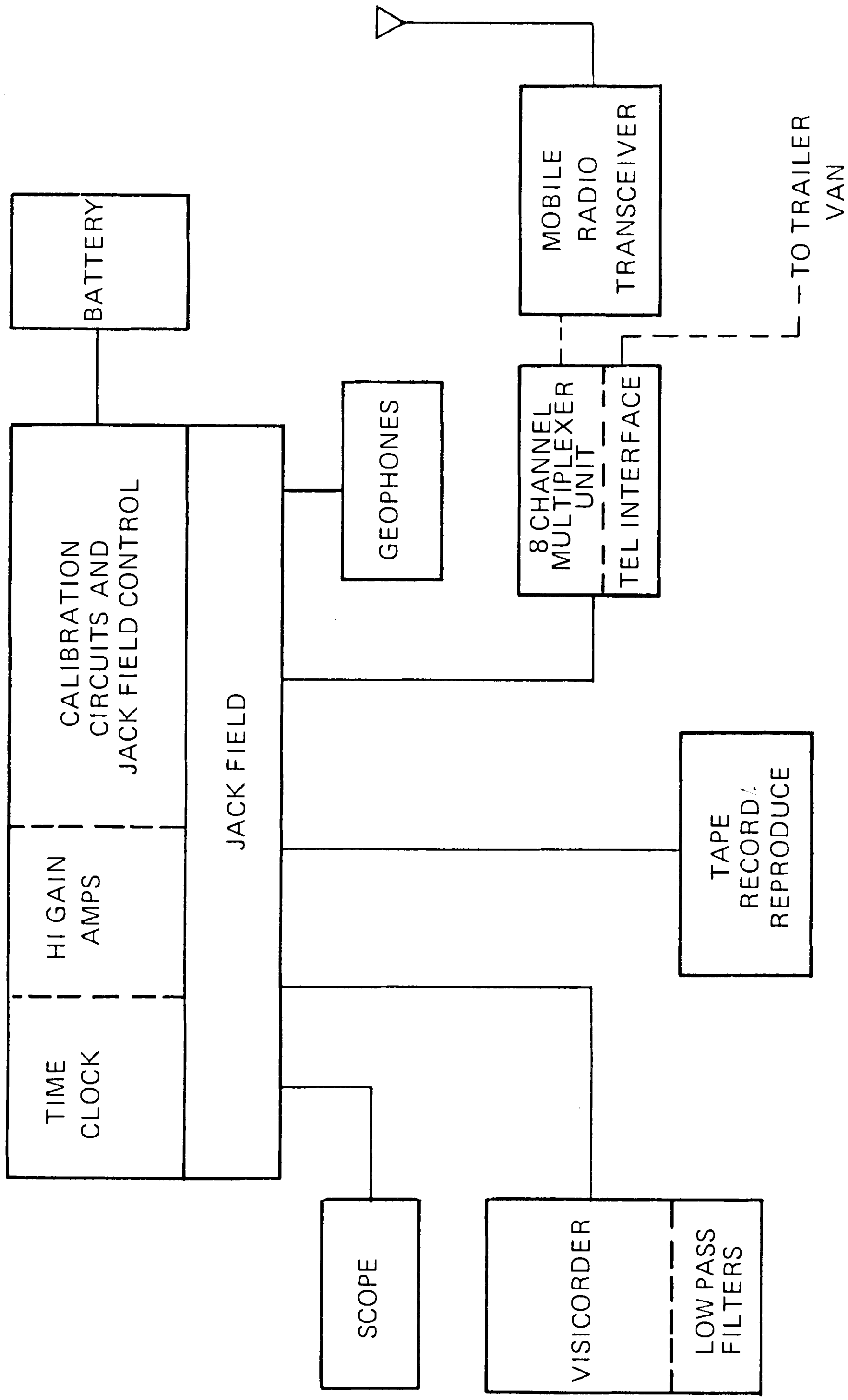
DEPLOYMENT:

- MODULAR PACKING
- PORTABLE PROCESSING CENTER

INSTRUMENTATION

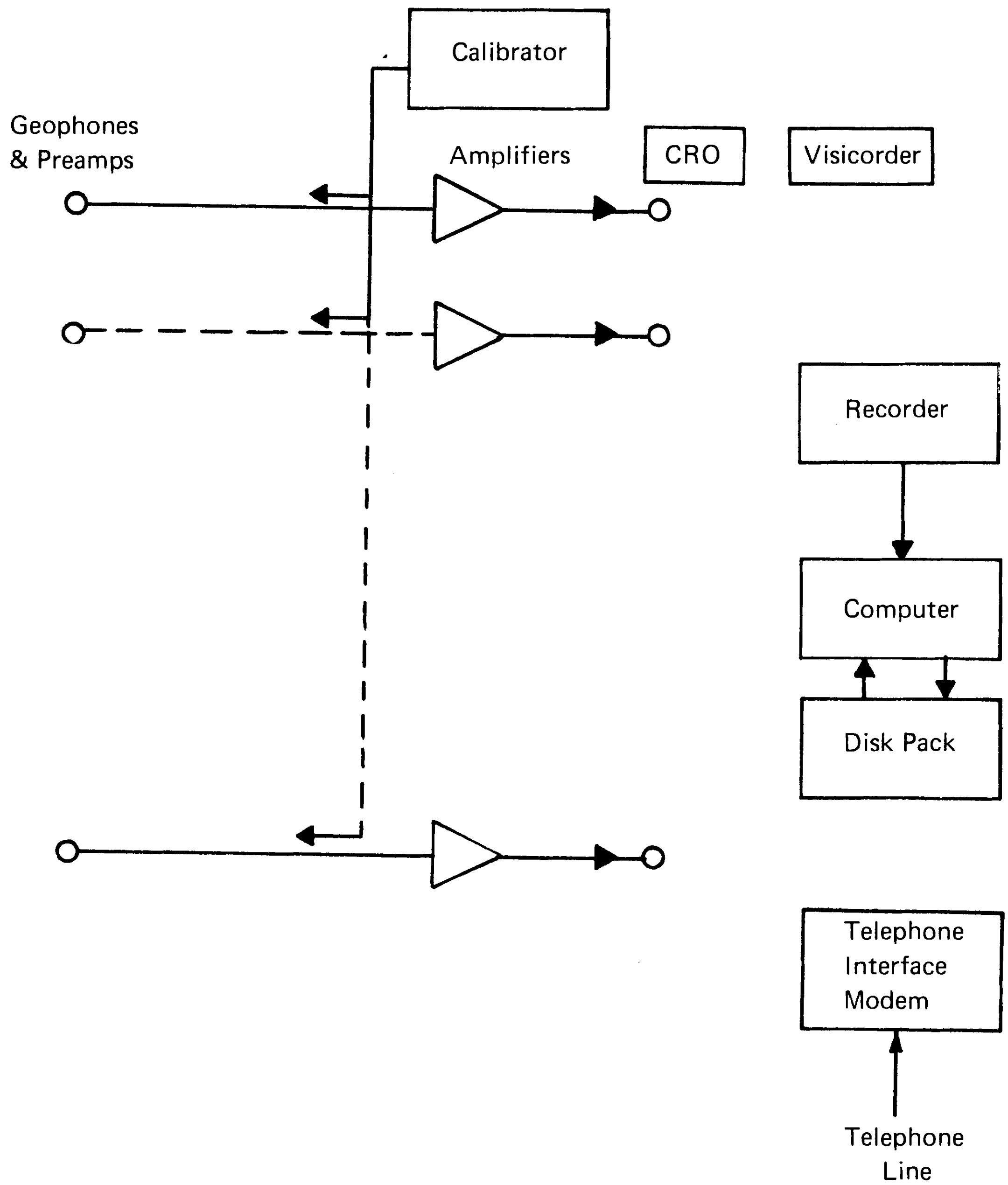
KEY ITEMS

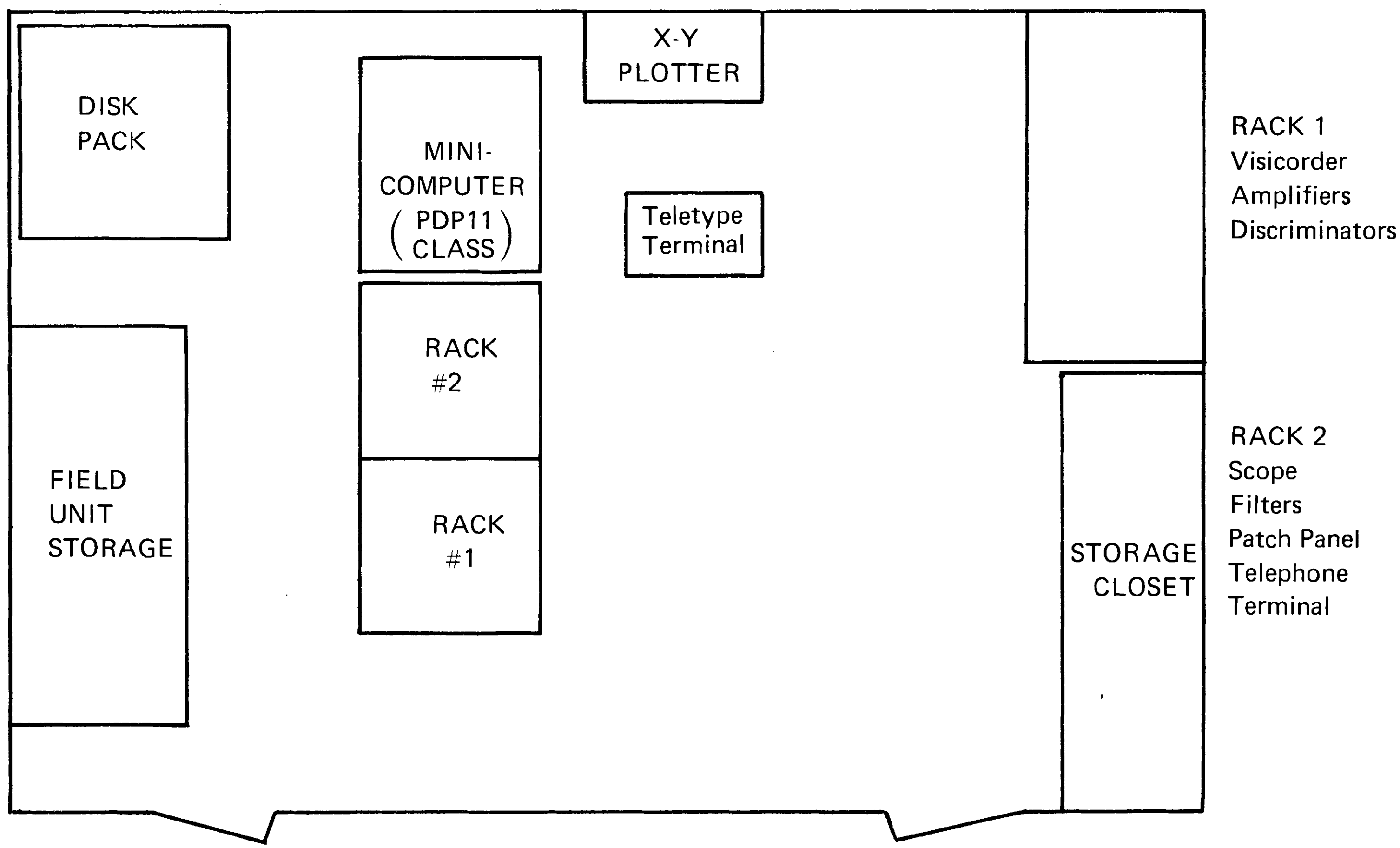
1. RAPID DEPLOYMENT OF DETECTION SUBSYSTEM
2. SELF-CALIBRATING SYSTEM - FRONT END AND FINAL OUTPUT - BOTH SENSITIVITY AND TIME
3. PERFORMANCE LIMITED ONLY BY SEISMIC NOISE
   - Geophone/Preamp Unit
   - Burial of Geophones
4. DISC PACK FOR COMPUTER
   - Fast Programming
   - Extends Capabilities
5. DISPLAYS
   - Real Time
   - Processed



SUGGESTED SEISMIC DETECTION SUBSYSTEM

BLOCK DIAGRAM INSTRUMENTATION

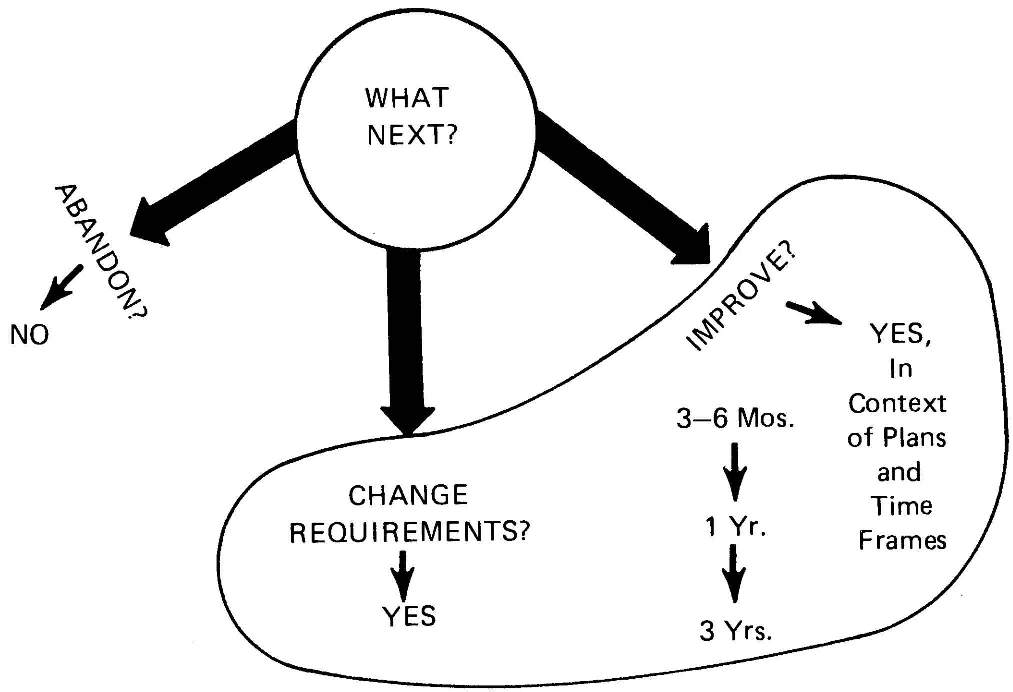




SUGGESTED TRAILER VAN SIGNAL PROCESSING AND LOCATION SUBSYSTEM

F. CONCLUDING REMARKS

ROBERT L. LAGACE


WHAT
NEXT?
ABANDON?
NO
CHANGE
REQUIREMENTS?
YES
IMPROVE?
YES,
In
Context
of Plans
and
Time
Frames
3–6 Mos.
1 Yr.
3 Yrs.

BIBLIOGRAPHIC DATA SHEET	1. Report No. ADL-C-73912-VOL. II	2.	3. Recipient's Accession No.
4. Title and Subtitle SURVEY OF ELECTROMAGNETIC AND SEISMIC NOISE RELATED TO MINE RESCUE COMMUNICATIONS. VOL. II. Seismic Detection and Location of Isolated Miners.			5. Report Date (Preparation) January, 1974
			6.
7. Author(s) Robert L. Lagace, et al.			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Little (Arthur D.), Inc. 25 Acorn Park Cambridge, Massachusetts 02140			10. Project/Task/Work Unit No.
			11. Contract/Grant No. USBM-H0122026
12. Sponsoring Organization Name and Address U.S. Department of the Interior, Bureau of Mines, Pittsburgh Mining and Safety Research Center, 4800 Forbes Avenue Pittsburgh, Pennsylvania 15213			13. Type of Report & Period Covered FINAL Aug. 1971 - Dec. 1973
			14.

15. Supplementary Notes

Initiated under the Coal Mine Health and Safety Research Program.

16. Abstracts Volume II of this report presents the findings of a short intensive assessment performed during the fall of 1972 by a task team composed of ADL staff and seven special seismic consultants, to provide the U.S. Bureau of Mines with independent technical judgments regarding the potentials and limitations of seismic methods and systems for: (1) detecting the presence of isolated signaling coal miners, (2) locating such miners to within the confines of a 600-by-600 foot mine section, and (3) further locating these miners to within a 15-foot entry width. The results of this assessment were obtained by addressing the following major subject areas treated in this volume: the detection of seismic signals and the estimation of their arrival times, the location of the origin of seismic signals, seismic signal source and propagation characteristics, earth models, seismic noise characteristics, signal-to-noise ratio improvement techniques, coal mine operational and emergency environments, seismic detection and location instrumentation and its effective utilization during mine rescue operations. Experimental seismic data gathered by others during a series of mine field tests prior to this task and other relevant seismic data were fully utilized for the assessment reported in this volume.

17. Key Words and Document Analysis. 17a. Descriptors

Mines-Coal	Seismic Noise
Coal Mines	Seismic Wave Propagation
Rescue Operations-Mines	Seismic Signal Sources
Miner Location	Seismic Instrumentation
Seismic Location	Through-the-Earth Communications-Seismic
Seismic Detection	

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 374
	20. Security Class (This Page UNCLASSIFIED	22. Price

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